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ENGINEERING OPERATIONS REPORT

Nerva
DRA

FINAL REPORT

PREMIUM QUALITY 5Al-2.5 Sn ELI TITANIUM PRODUCTION

PROJECT 121

MAY 1972

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1. M100-TPV07-W121, Turbopump Rotating Components Reliability Verification Program Plan, NERVA Program, Contract SNP-1, December 1970

2. Investigation of Plane-Strain Flaw Growth in Thick Walled Tanks, C. F. Tiffany et al, Boeing Co., February 1966, NASA CR-54837

3. DRM 04.04 dated 17 February 1971

4. ASTM-E399

5. Anamet Labs. Inc. Test Report No. 172.185 (P.O. N-02781), dated February 9, 1972

I. INTRODUCTION

Preliminary design and reliability analysis conducted on the turbopump for the NERVA 75K full flow cycle engine, indicated that the turbopump bearings were the most critical turbopump parts in meeting the 10 hour life at the required turbopump reliability of .99978. The analysis revealed that significant reductions (approximately a factor of 3.25) in bearing loads would be achieved by fabricating the rotating parts from titanium in lieu of A286 or 718. This is basically due to the difference in density of the materials and the resulting mass effect on the location of the first and second "stick mode" critical speeds. For the selected rotor configuration, the lighter material has a "first critical" speed at approximately 36,000 rpm, while that of the heavier material has a "first critical" at approximately 27,000 rpm. As the operating range of the turbopump is from 0 to 30,000 rpm, the heavier material would have a "stick mode" critical in the operating range.

The task of "selling" titanium as a rotor candidate material for a centrifugal turbopump started in 1966 and culminated in an agreement in June 1969 by SNPO-W to go ahead with the then current design. One outgrowth of this agreement (among many others) was that any titanium material used should be produced with ANSC specification control along each and every step of the production process, i.e., "cradle-to-grave" control. This requirement was imposed by SNPO-C in order to accomplish the following three major objectives:

a. Insure that parts for actual TPA use would be very similar (metallurgically) to parts used in test programs.

b. Insure that follow-on parts could be produced in a manner very similar to earlier produced parts (reproducibility).

c. Optimization of production through adherence to rigid specifications in order to attain the highest possible material and structural design allowables.

With these broad objectives in mind, ANSC was enjoined to abandon a rotor forging program using some existing heats of material available at the selected forging vendor. Instead, a period of four months in 1970 - 1971 was devoted to the conception, coordination and completion of three titanium specifications controlling the production and testing of titanium sponge, billets and forgings in support of a turbopump rotating components reliability verification program (Reference 1).

Production of titanium forgings adhering to these three specifications is the subject of this report.

II. SUMMARY

Titanium die and pancake forgings were produced using controlled billet material. The majority of the forgings produced were utilized for fabrication of turbopump component parts. The balance of the forgings were used for an interim material test program conducted to assess the results of producing material with ANSC specification control and to confirm the structural adequacy of the machined parts. Forgings ordered for specific test purposes, such as

extensive fracture toughness test programs, were not produced. An interruption of titanium production by a lengthy strike, which started in October 1971 and continued to the time of the writing of this report, prevented further material production.

Tensile and fracture toughness test programs were completed and verified the superior quality and mechanical properties of the subject material in both gaseous and liquid hydrogen.

It was theorized that TPA components would have had very high calculated reliabilities based upon the low flaw growth rates of the material in the operating environments of interest.

III. SPECIFICATIONS

The NASA guidelines specified that titanium material for rotating application was above all to be:

1. Completely traceable, back to the individual sponge lot history, and,
2. Completely reproducible, in order to minimize lot-to-lot variation.

In order to accomplish such requirements, a new forging specification had to be written, and specifications for billet and sponge material had to be developed since no industry specifications for billet and sponge were in existence.

In general, the following procedure was followed to insure that specifications were written which would meet the two overriding requirements stated above, and yet, would not be excessively burdensome for the titanium producers to work to:

1. Review of existing industry Ti 5Al-2.5Sn ELI bar and forging specifications, including:

   a. Aerojet-General Corporation

   b. North American-Rockwell/Rocketdyne

   c. Boeing Company

   d. Pratt & Whitney Division

   e. General Electric

2. Review of billet and sponge specifications, as available from the titanium producers and forgers.

3. Coordination and cooperation with the major titanium producers.

Using the above approaches, information was gradually accumulated which enabled the writing of three specifications covering each product form required. The input material and background for each specification is described below.

<u>Ti Sponge Specification, ANS 90296</u>

There were no existing sponge specifications at the time that this work was initiated. However, Reactive Metals Incorporated (RMI) made available an in-house sponge specification, RMI Ti-001, and the ASTM sponge specification, ASTM B299-69, which was based on RMI Ti-001, was also used. Somewhat after the fact, the P & W specification PWA 1201, Titanium Sponge, was used for comparison purposes, but it was loosely patterned after the ASTM specification, also, and contained nothing new. With the help of these documents and coordination with both RMI and Titanium Metals Corporation of America (TMCA), the ANSC Specification ANS 90296 was written, covering sponge production by the MgCl and NaCl processes. Several major features of this specification, included as Enclosure (1), were:

1. Requirement for 100% inspection.
2. Low sponge hardness (low oxygen content).
3. Stringent vendor reporting and certification requirements to enable future reproducibility.

Ti Billet Specification, ANS 90295

There was no existing titanium billet specification and reliance had to be placed on input material supplied by the billet producers, RMI and TMCA. In addition, rotating grade specifications used by Pratt & Whitney, such as F12 and E52, were used as models for testing and non-destructive inspection requirements. Subsequently, a section was added requiring in-process beta transus determination and finish forging below the beta transus temperature thus determined. The billet specification required billet traceability to the ingot and featured chemistry checks for each end of each billet, mechanical property testing and extensive non-destructive testing requirements. Some major features of the specification, included herein as Enclosure (2), were as follows:

1. Billet size restricted to 8 inch diameter.
2. No recycled material (scrap) to be used in melt.
3. Tight chemistry with 125 ppm H_2 limit.
4. Primary and secondary melting controls on vaccum and power.
5. Process controls on welding of electrode, cleaning and coating, macrograin and microstructure, and external and internal quality.
6. Ultrasonic inspection acceptance criterion of 3/64 inch max.
7. Extensive vendor reporting and certification requirements to insure future reproducibility.

Ti Bar and Forging Specification, ANS 90297

Several Rocketdyne and Aerojet Specifications were used to draft a premium grade pancake and die forging specification. The following reference material, among others, was used:

1. Rocketdyne Specification MB0170-010
2. Rocketdyne Specification RB0170-079
3. Aerojet Specification AGC-90163.

In addition, the forging industry was approached for useful suggestions and knowledgeable personnel at Battelle Memorial Institute, Boeing Company and Lockheed Aircraft Company were personally contacted.

The specification differed from conventional titanium specifications in that it covered bars as well as both die and pancake forgings. The chemistry was tightened to make it consistent with the billet specification and, of course, only ANS 90295 billet material was allowed for the forging input material.

In order to insure high component reliability (by optimizing fracture toughness), a very tight ultrasonic inspection acceptance criterion was imposed on the two selected forgers. This criterion included a 1/64 inch maximum diameter acceptance standard, as well as both longitudinal and shear wave inspection and C-scan recording in order to provide a permanent record of the internal quality of each forging. One of the selected forgers accepted this requirement; however, the other forger would commit only to provide forgings to the more standard requirement of a 3/64 maximum indication.

In order to minimize absorption of embrittling gas species, parts were vacuum annealed and, then, rapidly cooled, to preclude the formation of embrittling microstructural phase transformations.

Mechanical properties were raised to higher than previously accepted limits, including high ductility requirements.

A copy of the final version of the specification, ANS 90297, is included as Enclosure (3), and contains the following additional provisions:

1. Tighter H_2 and O_2 content.
2. Surface quality with a tight (1/64 inch) flaw size acceptance level.
3. Very fine equiaxed microstructure requirement.
4. Inspection and evaluations of a forging "try-out" to verify the adequacy of the forging practice.

5. Extensive vendor reporting and record keeping requirements to insure future reproducibility of the part.

The three specifications described above were extensively coordinated by conferences and meetings with the affected organizations, including the titanium producers, major forging vendors, internal ANSC engineering and quality control organizations and NASA SNSO-C and SNSO-W engineering and quality control organizations; the latter verified the specification scopes and contents, in turn, with NASA-Lewis Research Center and the Naval Research Laboratory. Final approval was obtained, late in 1970, from all affected organizations, enabling release of the specification and paving the way, after approximately five months, for material procurement action.

IV. MATERIAL ORDER AND PRODUCTION

A. HEAT K8930 (TMCA)

Five thousand pounds of 8-inch diameter billets, in 10-12 foot random lengths, was ordered from the Titanium Metals Corporation of America (TMCA). The billets were ordered to conform to ANS-90295A and applicable sub-specification ANS-90296A (sponge), as well as ANS-9032, a quality standard applicable to inspection of, and acceptance criteria for, surface flaws. An additional requirement imposed on the producer originated with the primary forger (Arcturus Manufacturing Company), who required that the billets be finish forged below the beta transus temperature, Enclosure 4, in order to optimize subsequent die-forgeability. Additional, minor, deviations requested by TMCA are included herein as Enclosure 5.

Source surveillance started with on-the-spot inspection of the 8600 pounds of sponge planned for use in this procurement. The sponge was conveyed past inspectors at the rate of 700 pounds/hour. Non-metallic contaminants and discolored sponge particles were removed by hand.

X-ray inspection enabled discrimination between normal density titanium and high density contaminants. On the whole, the sponge appeared to be uniform in size and clean. Very little contamination or discolored sponge was found. Heat data made available by TMCA is included in Enclosure 6.

Following inspection of the sponge, a meeting was held concerning production procedure documentation. TMCA had prepared an operations procedure document for ingot manufacture. In it, new and additional exceptions to ANSC Specification ANS-90295, covering electrode melting requirements, were presented. The exceptions had to do with secondary melting cycle vacuum control and power control requirements. It appeared that the pressure level must purposely be increased at the end of the second melting cycle in order to control the arc. To have held TMCA to 1000 microns throughout the second melting cycle would have constituted a major process deviation for them and could have unfavorably affected the ingot quality. Finite power interruptions also had to be allowed due to arc characteristics during second melting.

Following inspection, the sponge was split into 24 weighed, equal portions. Aluminum and tin additions, weighed out against pre-calculated requirements, were added by hand; iron powder and titanium oxide were also added. Finally, each of 24 barrels contained sufficient material to produce one compact weighing approximately 300 lbs.

B

Following a two-minute mixing cycle, the input materials were cold pressed in an 8000-ton press into 24 semi-cylindrical compacts. Alloy content of each compact was preplanned according to the compact location in the electrode during melting. Accordingly, the input for compacts were numbered 1 through 12 for each of the A and B electrodes and came off the press in the proper order. This was necessitated by the varying mixing action from the top to the bottom of the electrode during the melting cycle.

Compacts were conveyed from the press to the welding area where they were plasma fusion welded together under Argon. Following welding, the welds were wire brushed and blown clean. At this point, each electrode was ready for primary melting.

The "A" electrode was assembled to a header and lowered into a sub-surface, pre-cleaned crucible. The crucible was evacuated to approximately 500 microns; water cooling systems, for cooling of the crucible, had been checked previously to insure against leaks.

Melting of the "A" electrode, followed by melting of the "B" electrode on top of the "A" melt, proceeded without incident. A vacuum level of 700 microns was maintained throughout the primary melting cycle. The voltage and amperage levels and fluctuations appeared to be normal and, according to TMCA personnel, the primary electrode looked typical.

Subsequent processing of the electrode was carried out by TMCA (without ANSC surveillance) as follows: The primary electrode was cleaned by high pressure water spraying and acid pickling. A holding assembly was welded in place and the second vacuum melt was conducted.

ANSC was informed that the second melt was typical, interrupted only by several momentary voltage spikes due to arc shorting. Vaccum was maintained at from 300-350 microns during the melting (compared to 1000 microns allowed in the ANSC Specification). Following the final melt, the ingot was machined and prepared for shipment to the TMCA forging plant in Toronto, Ohio where the ingot was scheduled to be reduced to the 8-inch diameter billets ordered by ANSC.

Ingot chemistry, prior to shipment, was determined, as shown below, and was acceptable according to ANSC Specification ANS-90295.

	CHEMISTRY OF ANSC HEAT K8930	
ELEMENT	HEAT K8930	ANSC 90295
Aluminum	4.9	4.7 - 5.6
Tin	2.3	2.0 - 3.0
Manganese	0.003	0.03 max.
Iron	0.165	0.25 max.
Oxygen	0.078	0.12 max.
Carbon	0.026	0.05 max.
Nitrogen	0.0085	0.04 max.
Hydrogen	0.003	0.0125 max.
Chromium	<.001	0.05 max.
Molybdenum	<.001	0.05 max.
Vanadium	<.001	0.05 max.
Magnesium	<.001	0.05 max.

ANSC surveillance was now transferred to TMCA's Toronto, Ohio Plant, where ingots are received, conditioned, and forged.

The ANSC ingot was received by the Toronto, Ohio mill in the rough-turned condition. A refractory protective coating was then applied to the ingot prior to heat-up to minimize hydrogen pickup.

The ingot was heated to 2200°F in preparation of upsetting from 70-inch long to 49-inch long, followed by the sequence of heating, forging and cooling events shown in Enclosure 7.

The ingot forging was completed successfully and expeditiously, and mill schedules were changed to finish forging as quickly as possible. Extra forging steps and precautions were taken to optimize the material quality, such as ingot upsetting, water quenching, 1840°F finish forging temperature and insertion of the intermediate 9-1/2 inch diameter forging step.

The T and T2 bars were scheduled to be shipped to Arcturus Manufacturing Company for use in rotor forgings, depending on ultrasonic, mechanical property and micro and macrostructure test results of the five billets produced.

The billets were prepared for nondestructive inspection by lathe turning to a surface finish of 125 RMS. In accordance with Specification ANS-90295A, the billet inspection standard was to be made using a piece of randomly selected billet.

The material initially selected for ultrasonic calibration standards was taken from the top end of the billet that had been identified as "B", having been forged from the bottom portion of the ingot. The supplier was unable to calibrate the ultrasonic settings to the standards made from the

"B" billet due to high noise and low penetration caused by excessive scatter and absorption. An evaluation and comparison of noise levels in the actual billets were made, and it was determined that ultrasonic calibration standards could be developed from the bottom portion of the "T" billet. New calibration standards were fabricated from the "T" billet and ultrasonic settings were successfully calibrated for longitudinal and shear wave testing. Billets beginning with "T" through "T-4" (including "B") were longitudinally and shear wave tested and no discrepancies were detected. The noise levels experienced at the start, half way through and at the end of each billet were recorded. A back reflection test was tried on two billets, only, and the testing of the balance of billets discontinued. Set up for back reflection was made and started from the top end of the billet and, at about a fifth of the length, the loss of back reflection exceeded fifty percent. When the setup was made at the opposite end (at the bottom end of the billet) all billets passed the back reflection test. Conversely, all billets failed to pass the test on setups made from the top end of billets. From the ultrasonic back reflection test results observed, the supplier advised these tests would have no meaning. In addition, it was learned that there had been a temperature gradient in the furnace from the front to the back end during the heating for the forging process. The bottom ends of the billets were located at the back end of the furnace and the top ends in the front at a lower temperature. Macrostructure photos confirmed that lower temperatures were experienced at the top ends of the billets. The ultrasonic noise levels experienced during testing tended to follow the same pattern in each billet. Enclosure 8 shows the material source for, and the design of the ultrasonic standards used. Non-destructive testing is discussed in Section VI of this report.

Complimenting the ultrasonic loss of back reflection due to microstructure, it was determined that the beta transus temperature limit had been violated during billet forging; beta transus checks made after the billet processing had been completed indicated that the beta transus was inordinately low, 1830°F, probably due to the rigorous production and chemistry controls imposed by ANSC. Consequently, final forging was carried out at up to 10°F above the beta transus.

Extensive microexaminations were conducted on all five TMCA billets. Results of these examinations are described in Figures 1 thru 14 and below:

BILLET S/N	LOCATION IN BILLET	TYPE OF ALPHA STRUCTURE	REFERENCE FIGURE NO.
T	Top	Partly equiaxed alpha	1, 2
(Top of Ingot)	Middle	Transformed, fine alpha	3
	Bottom	Transformed, fine alpha	4
T2	Top	Partly equiaxed alpha	5
	Bottom	Transformed alpha	6
T3	Top	Equiaxed alpha	7
	Bottom	Transformed alpha	8
T4	Top	Partly equiaxed alpha	9
	Bottom	Transformed alpha	10
B	Top	Equiaxed alpha	11, 12
(Bottom of Ingot)	Bottom	Partly equiaxed alpha	13, 14

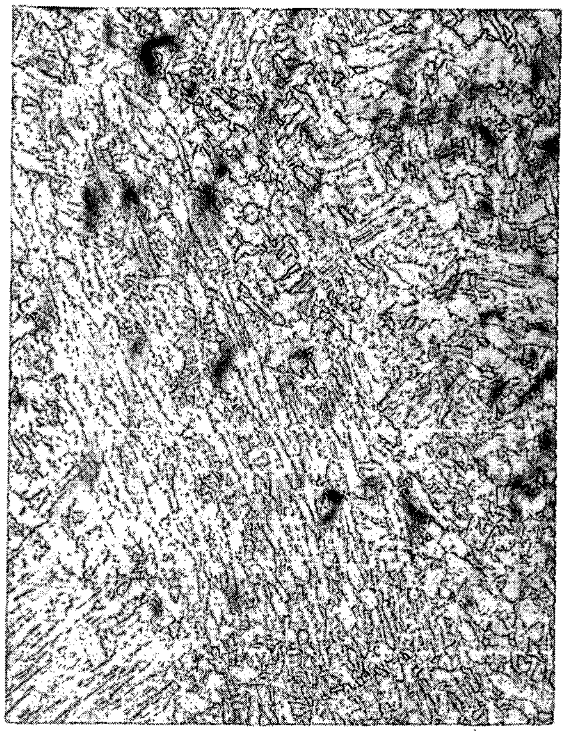


Figure 1

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 3/4 inch from surface of top of T billet.

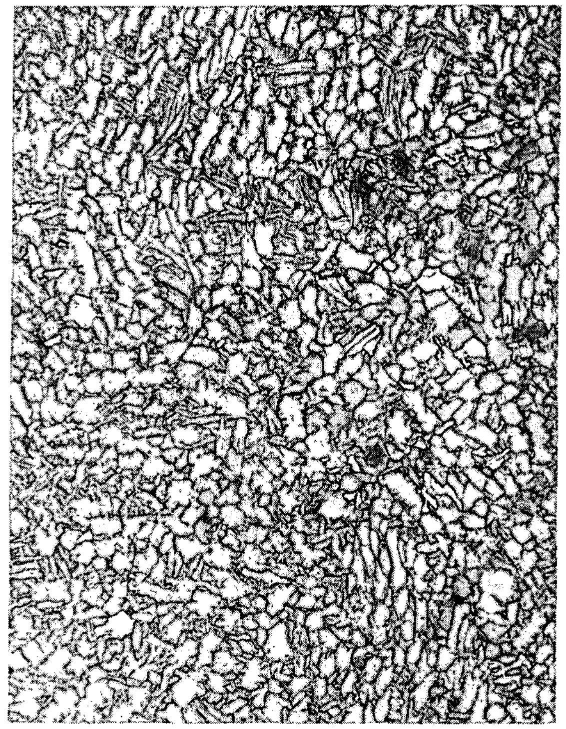


Figure 2

Heat K8930 100X
HNO_3/HF etched.

Predominantly equiaxed alpha 2 in. from surface of top of T billet.

Figure 3

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 1 1/2 inch from surface at mid-length section of T billet.

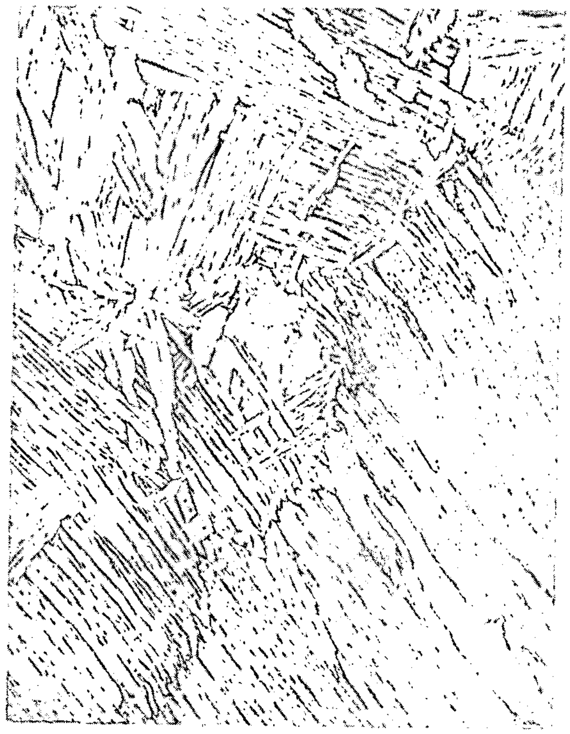


Figure 4

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 2 in. from surface at bottom of T billet.

Figure 5

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 0.9 inch from surface at top of T2 billet.

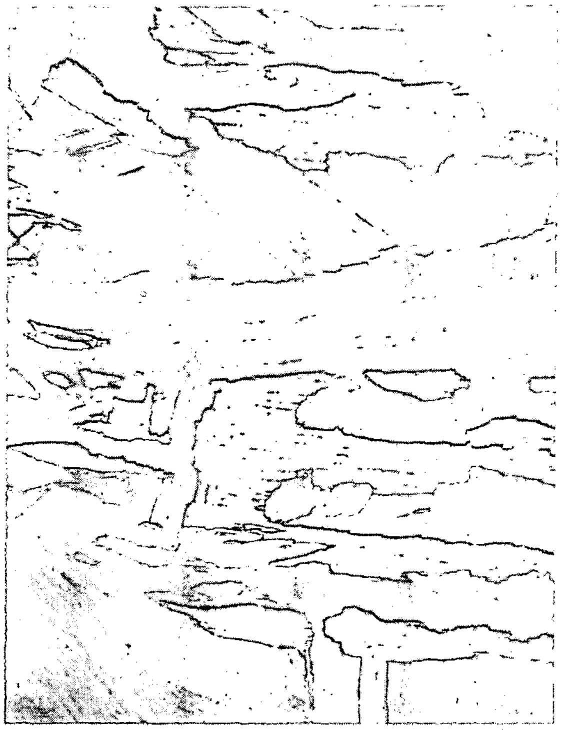


Figure 6

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 2 in. from surface at bottom of T2 billet.

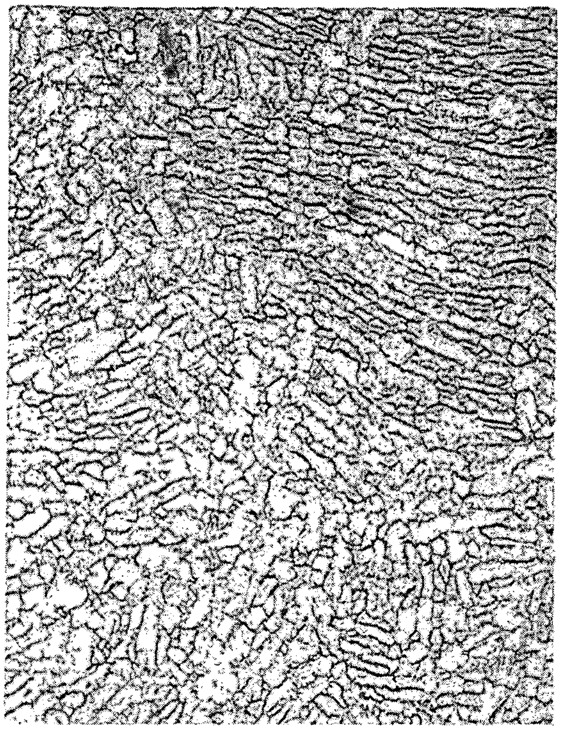


Figure 7

Heat K8930 100X
HNO_3/HF etched.

Predominantly equiaxed alpha 2 in. from surface of top of T3 billet.

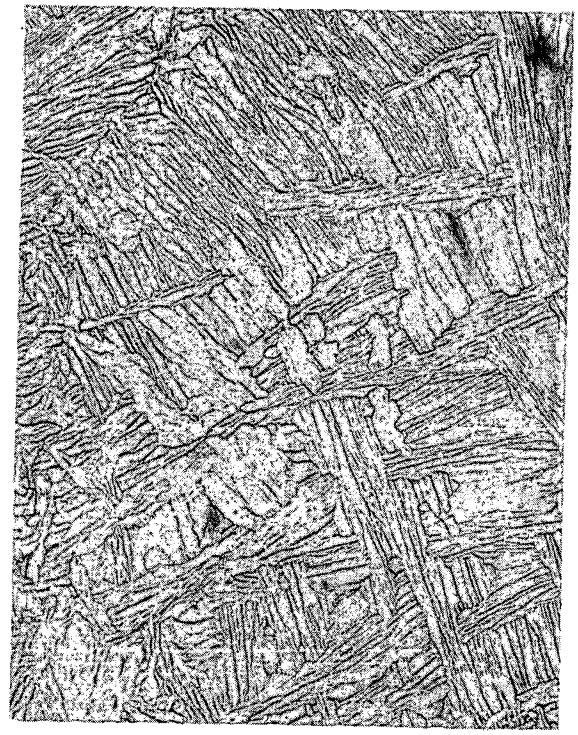


Figure 8

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 2 in. from surface of bottom of T3 billet.

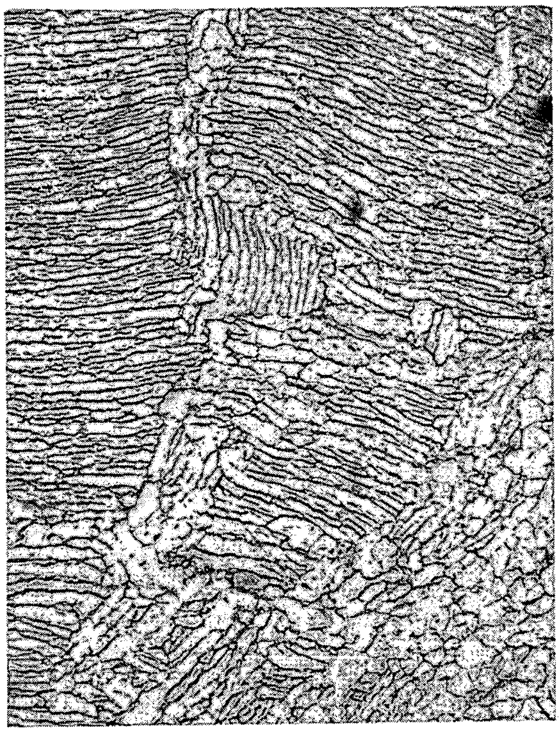


Figure 9

Heat K8930 100X
HNO_3/HF etched.

Mixed equiaxed alpha 2 inch from surface of top of T4 billet.

Figure 10

Heat K8930 100X
HNO_3/HF etched.

Transformed alpha 2 inch from surface of bottom of T4 billet.

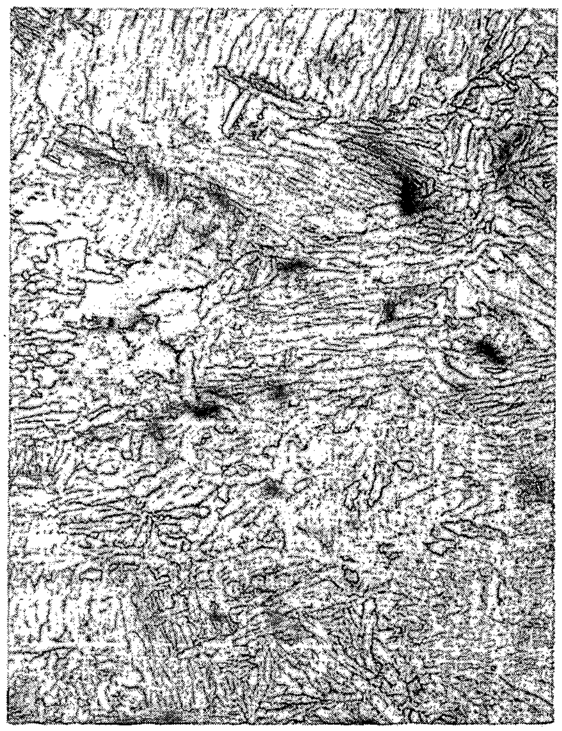


Figure 11

Heat K8930 100X
HNO_3/HF etched.

Mixed alpha 0.9 inch from surface of top of B billet.

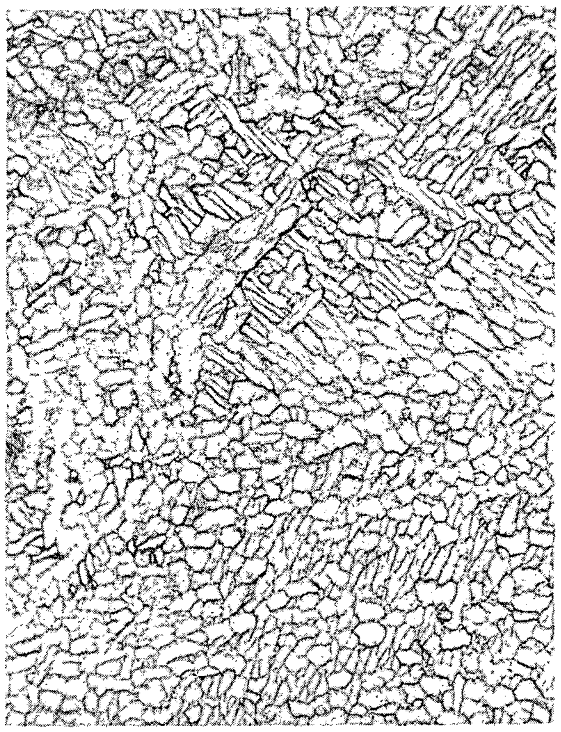


Figure 12

Heat K8930 100X
HNO_3/HF etched.

Equiaxed alpha 2 inch from surface of top of B billet.

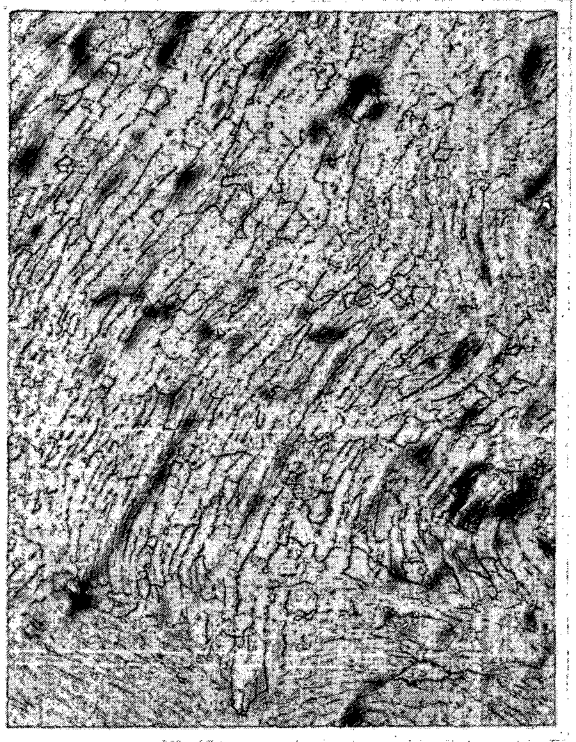


Figure 13

Heat K8930 100X
HNO_3/HF etched.

Mixed alpha 1.05 inch from surface of bottom of B billet.

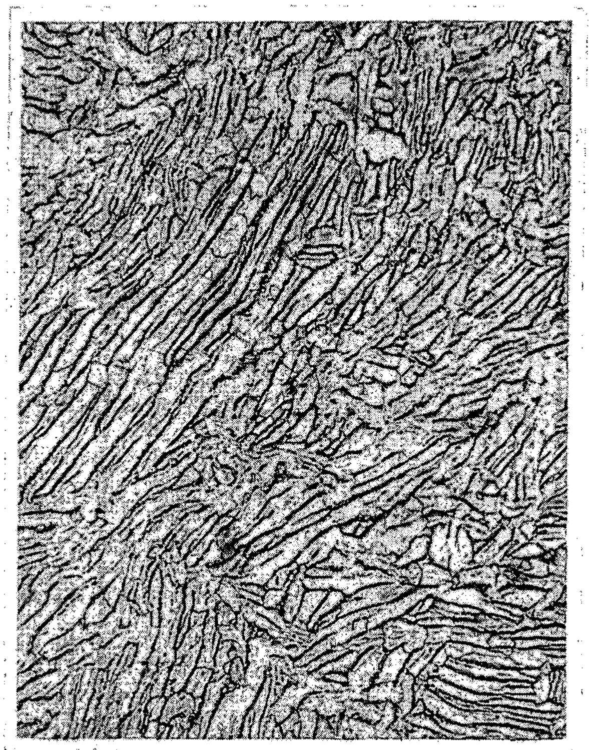


Figure 14

Heat K8930 100X
HNO_3/HF

Mixed alpha 2 inch from surface of bottom of B billet.

The above results indicated that the billets had been subjected to a 20-30°F thermal gradient which apparently bridged the 1830°F beta transus, causing some parts of each billet (except the B billet) to exhibit a transformed alpha microstructure. Since large portions of four billets were affected, there was no possibility of cropping and rejecting such affected areas. Subsequent telephone coordination with Arcturus Manufacturing Company indicated that the transformed alpha microstructure could be satisfactorily forged-out by cross-forging the material prior to the final die-forging. This was to be accomplished by heating and forging cycles which break-up and agglomerate the fine alpha platelet structure. The forgeability of the material was demonstrated by TMCA. A two-inch thick slice was forged down to 3/4 inch at a forging temperature of 1750°F. Test results, shown in Table I, indicated satisfactory forgeability and mechanical properties in excess of those reqired by the ANSC titanium forging specification, ANS-90297.

TABLE I

ROOM TEMPERATURE MECHANICAL PROPERTIES OF TMCA Ti 5Al-2.5 Sn ELI HEAT AFTER FORGE - DOWN FROM 2-INCH THICK SLICE

HEAT NO.	PRODUCER	UTS (KSI)	TYS (KSI)	% EL. IN 2 IN.	% R OF A
K8930*	TMCA	122	113	14	30
ANS-90297	(Requirement)	110	100	12	25

*Average of four tests.

On the basis of the acceptable macrostructure, as required by Specification ANS-90295, the exceptionally good mechanical properties shown in Table I and Arcturus' indicated ability to alter forging practice to accommodate billets with transformed alpha microstructure, the billets were considered metallurgically acceptable and were expected to produce satisfactory die forgings. Consequently, it was decided to ship all five billets to both Arcturus Manufacturing Company and Carlton Forge (the second forger). Certifications of shipments, including individual billet characteristics and forge-down tensile properties, are presented in Enclosure 9.

B. HEAT 804722 (RMI)

1. <u>Production per ANS-90295A</u>

In order to obtain a broadly based statistical design allowable for fracture toughness properties, a second 5000-pound heat of billet material was ordered from Reactive Metals, Incorporated (RMI). Billets were ordered in the same 8-inch diameter size and in 10-12 foot random lengths. Billets were to conform to the same specifications as discussed above, and, again, a finish forging temperature limit was imposed, Enclosure 10.

Source surveillance started during the early stages of the electrode build-up.

RMI sponge was examined after it had already been split into small portions contained in paper bags. Although very little sponge could be inspected, it appeared to be uniform in size, clean and free from oxide discolorations.

The sponge was weighed out from an elevated tote bin into pre-placed brown paper shopping bags. Premixed portions of aluminum, tin and iron were drawn into the bag along with the sponge. The manner of feeding the input materials into each bag had the effect of distributing the alloying materials into layers which were easily discernible after compacting of the mixture.

The 352 bags, loaded with 27-1/4 pounds of sponge and alloy, were now ready for compacting into 88 electrode sections. Input material identification was as follows:

Sponge Lot 1184 I - 3054 lbs	)	
Sponge Lot 1186 I - 3273 lbs	)	Sponge Blend 4774
Sponge Lot 1187 I - 3331 lbs	)	

(Not all of the above sponge lots were used.)

Chemistry certifications of sponge lots met the requirements of ANS-90296-3.

Certification of alloying elements indicated the following lots were used:

Aluminum pellets - Lot 67
Tin Wire - Lot 63
Iron Clippings - Lot 67

Compacting was performed by emptying the contents of three bags of material into a die cavity. Following pressing, a fourth bag was added and pressed, resulting in an approximately 109-pound compact. Forty-four of these were aligned in a rack, tied together by steel straps and prepared for welding.

The RMI compact welding method was superior to TMCA's in that welding was performed in a sealed and evacuated (to 500 microns) glove box, subsequently back-filled with 1/2 psia of Argon. Welding was performed by arc welding with commercially pure welding rod made from 3/8 inch thick plate. In addition to welding the compacts together, a lifting and handling section called a header was welded to the electrode using four Ti 5Al-2.5 Sn ELI straps approximately four inches wide by 1/2 inch thick, called spacer bars.

Spacer bars were assembled such that the length from the top of the header to the bottom of the electrode was compatible with the crucible depth during melting. Approximately four hours were required to make the many compact-welds required to hold the electrode together for melting.

Welding material identification was as follows:

Weld Rod:	Grade 446 Lot 779
Spacer Bars:	Grade 461 Lot 338
Header:	Heat 293110 - 462B

The appearance of both the A and B electrodes was similar; i.e., welds were clean and shiny but adjoining areas were covered by a black deposit. Several RMI personnel were contacted relative to the black deposit before a consensus was reached that the black material was a titanium oxide caused by heat-up in a partial vacuum. Since oxide is needed in the alloy, RMI refused to remove the black deposit.

A crucible was selected which was water cleaned and wire brushed, rather than sand blasted. The crucible was assembled to a furnace and the A electrode installed. Routine water and vacuum system checks were made followed by primary melting of the electrode. Vacuum was recorded by visual checking of vacuum level displayed on a portable Stokes Vacuum Gage. Melting was normal and was conducted at normal amperage and voltage levels and at a vacuum level of 200-400 microns.

Appearance of the ingot following melting was typical, according to RMI. The header from the B electrode was intact, as were the spacer bars and 1/2 of the top compacts; i.e., no header/spacer material was melted into the ingot.

The second vacuum melting was not witnessed by ANSC personnel, but it was reported by RMI that it was as successful and uneventful as the primary melting cycle. The resultant 30-inch diameter ingot was prepared for breakdown to billets. However, a change was requested by ANSC requiring that only two 8-inch billets be made and that the remaining material be retained in the 19-inch square intermediate stage in case titanium housing components were needed in the future. RMI had geared their processing operations through a series of forging steps of progressive size levels with specified heat treatments for each of the forging size levels in order to achieve the specified chemical and physical properties per ANS-90295/A when the forging processing was complete for the eight-inch diameter billets. RMI advised, in order to obtain these specified properties per ANS-90295/A for the nineteen-inch billet, they would have to make a complete reassessment and replan their processing operations. The processing of the ingot had been initiated in the shop; in fact, the ingot had been in the furnace several hours in preparation for the first forging operation. Stopping operations at this time (in order to design and develop new processing procedures for the nineteen-inch billets), RMI advised, might have disastrous results. It was decided to continue with the operations as planned for the first forging operation and in the interim, resolve the nineteen-inch billet procurement with ANSC. Subsequently, RMI and ANSC determined that when the forging operations, as initially planned by RMI, had progressed to the nineteen-inch square size, the billet would be parted. Sufficient material was to be removed from the top portion of the nineteen-inch square billet to provide for the fabrication of two eight-inch billets ten to twelve feet in length. The remaining (bottom) portion of the nineteen-inch square billet was to be retained pending resolution and further instructions from ANSC. RMI continued processing the eight-inch diameter billets from the top portion of the nineteen-inch billet.

The first forging operation involved upsetting, whereby the thirty-inch diameter by seventy-eight-inch long ingot was compressed to thirty-one inches in length and drawn longitudinally to a thirty inch square cross section. In a series of concurrent heat treating and forging operations, the thirty-inch billet was drawn longitudinally to a twenty-four inch square, and then to a nineteen-inch square. The billet was allowed to cool sufficiently for hot grinding of the surface to remove surface defects. After grinding, the nineteen-inch billet was annealed, cooled and cold cut to remove (from the top portion) material for the two eight-inch diameter billets. RMI continued processing the removed top portion through heat treating and forging procedures as follows: The nineteen-inch square was drawn longitudinally to a sixteen-inch square and subsequently to a twelve-inch octagon. Again, after sufficient cooling, the billet was hot ground. When completely cooled, the billet was cut into two pieces. The two 12-inch octagon cross section billets were then successfully converted to 8-3/8 inch diameter billets. After cooling, the billets were reidentified by stamping on the diameter at the top end of each billet; the first billet was identified with the letter "T" and the second billet, "T1".

Photographs of the microstructures at the top ends of the two billets produced by RMI are shown in Figures 15 and 16. RMI also overestimated the beta transus temperature and instead of 1890°F, the beta transus was determined to be 1840 ± 15°F. Consequently, RMI also forged the billets at, or just above, the beta transus temperature. As in the case of TMCA, the reason given by RMI for this error was the better than average purity of the sponge used and its lower than usual oxygen content. Again, after consulting Arcturus Manufacturing Company, it was determined that adequate leeway existed in the titanium forging practice at Arcturus to permit satisfactory cross and die-forging of this billet material.

Arcturus had a reputation in the titanium industry for attempting to force reforms aimed at improving the microstructure of titanium billets. In the past, Arcturus had to absorb losses from forgings which were scrapped because of improper billet microstructure; they had that experience with many heats of Ti 6 Al-4V and blamed it on improper temperature control during billet forging. Arcturus obtained their portable polishing device in order to enable them to perform metallographic examinations anywhere on a billet surface. Where billet microstructure was clearly unacceptable, the

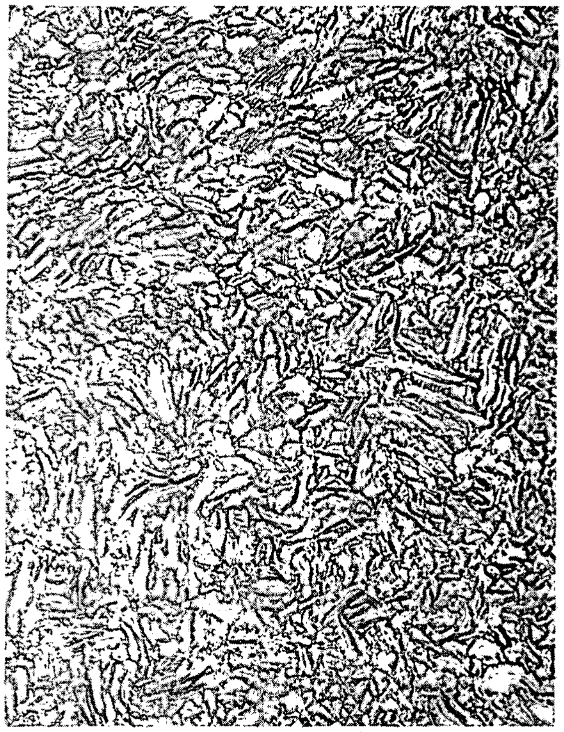


Figure 15

Heat 804722 100X
HNO_3/HF etched.

Transformed alpha in top of
T billet.

Figure 16

Heat 804722 100X
HNO_3/HF etched.

Transformed alpha in top of
Tl billet.

billet was rejected and returned; however, in marginal cases, Arcturus had success in improving the billet microstructure by subcritical cross-forging; i.e., upsetting and drawing forging multiples at temperatures well below the suspected beta transus temperature. The technique was not radical, but had been proven,and was considered particularly suitable to the ANSC material due to the small billet diameter and low input weights required for the relatively small rotor forgings.

The ultrasonic characteristics of the RMI billets verified the transformed nature of the alpha structure; i.e., the noise level was low and within the limits of ANS-90295A.

No defects in excess of 3/64 inch diameter were noted.

The fine macrograin, good mechanical properties and satisfactory ultrasonic characteristics of these billets were expected to result in satisfactory die-forgings.

Subsequent to processing of paperwork documenting the above deviations, the billets from RMI were shipped to the forgers.

2. Production per ANS-90295B

Following the forging, by both TMCA and RMI, of their respective heats of material above the beta transus temperature, a work stoppage was imposed on the forger by SNSO. After a series of meetings between SNSO, ANSC and Arcturus Manufacturing Company, it was concluded by SNSO that the material shipped to date would only be acceptable for TPA S/N 1; further TPA components, and the parts needed for the 144 test Ki program, would require material which had been forged below the beta transus in order to assure future reproducibility. A revision to the billet specification was effected and the 3200 lbs of material retained at RMI in the form of 19 inch square billet was to be finished in accordance with ANS-90295B. The first requirement was to make an accurate determination of the actual beta transus. The following procedure was used:

The nominal beta transus temperature of RMI heat 804722 was redetermined. The material used for the determination came from the top of the "T" billet. A 2-inch slice which had been previously forged down to 1/2 inch thick at 1750°F was further reduced to 0.150 inch thick by rolling at 1700°F. A heavily forged microstructure is preferred for alpha and beta transus determinations because small incremental changes in recrystallization temperature bring about noticeable effects in microstructure.

A Satec cylindrical furnace, used for tensile specimen heating, was used for the transus determinations. Three thermocouples were located at 6-3/4, 8-1/4 and 9-3/4 inches from the furnace top. The titanium sample was to be located in the furnace area corresponding to the 8-1/4 inch thermocouple location. Chromel-alumel thermocouples, prechecked against a standard were used.

The furnace was calibrated at settings of 1750, 1800 and 1850°F. The furnace was then reset to 1750°F and recalibrated prior to inserting the first beta transus specimen, with the results shown in Table II.

TABLE II

BETA TRANSUS FURNACE CALIBRATION RESULTS

FURNACE TEMP. SETTING °F	THERMOCOUPLE #1, 6-3/4 IN. FROM TOP	THERMOCOUPLE #2, 8-1/4 IN. FROM TOP	THERMOCOUPLE #3, 9-3/4 IN. FROM TOP	RANGE °F
1750	1755	1748	1744	11
1800	1797	1801	1804	7
1850	1851	1851	1856	5
1750	1745	1748	1748	3

Based on the above, a beta transus temperature correction of 5°F was applied (one-half the maximum beta transus furnace calibration range). However, since each beta transus determination specimen was closely monitored by the #2 thermocouple, the temperature correction cited above was conservative by a factor of 2.

Following the furnace calibration, 1/2 inch x 1 inch titanium specimens were suspended into the furnace such as to be adjacent to the #2 thermocouple. Specimens were introduced at 10°F intervals, starting at 1750°F, soaked 30 minutes and water quenched. The specimens were steel stamped 1 through 12 with the #1 specimen retained in the "as-rolled" condition. During the 30 minute soak at temperature, thermocouple readings were taken at 5 minute intervals in order to determine the temperature variation at each setting, as shown in Table III.

TABLE III

BETA TRANSUS DETERMINATIONS

FURNACE TEMPERATURE VARIATION

SPECIMEN NO.	FURNACE SETTING, °F	MAXIMUM TEMPERATURE VARIATION OVER 30 MIN SOAK, °F (#2 THERMOCOUPLE ONLY)
2	1750	1
3	1760	1
4	1770	0
5	1780	3
6	1790	5
7	1800	4
8	1810	3
9	1820	2 (Highest: 1819°F)
10	1830	4 (Lowest: 1828°F)
11	1840	3
12	1850	2

Following quenching, the specimens were metallographically prepared by polishing and etching with nitric-hydrofluoric acids. Careful examination of sections parallel to the specimen rolling direction indicated that the alpha transus may have been in the 1780-1790°F region; however, the first evidence of alpha prime was difficult to resolve at the relatively low magnifications used (up to 500X). The beta transus, at which all alpha is present as a transformation product, was easily determined to be between 1820° and 1830°F. Therefore, the nominal beta transus temperature for Heat 804722 was 1825°F. A furnace chart record of the lab furnace calibrations as well as each beta transus heat-up and soak is included as Enclosure (11).

Photomicrographs of the "as-rolled" microstructure as well as each as-quenced beta transus microstructure are presented in Figures 17 through 28.

The determinations described above satisfied two of the three variables required for establishing the maximum finish forging temperature, viz., the nominal beta transus, 1825°F, less one-half the maximum lab furnace variation, 5°F; determination of the remaining variable, the forge shop furnace calibration is described below.

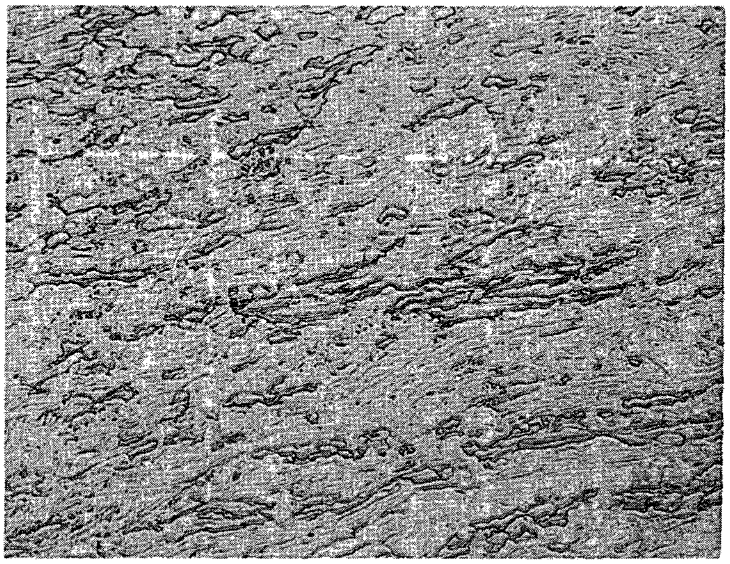
Finish forging of Heat 804722 19-inch billet required a furnace temperature survey of the furnace, or furnaces, which RMI planned to use. Accordingly, RMI had rebricked the door of Furnace #42 and had made various calibration runs at 1950 and 1800°F, as shown in Enclosures (12) and (13). Following some control instrument adjustments, the furnace demonstrated an overall temperature variation of 37° at 1800°F. The furnace zone that was covered in all these calibrations is defined by the following dimensions:

The central 15 feet along the furnace length
(Total Length is 21 feet)

The central 7 feet of the furnace width
(Total Width is 13 feet)

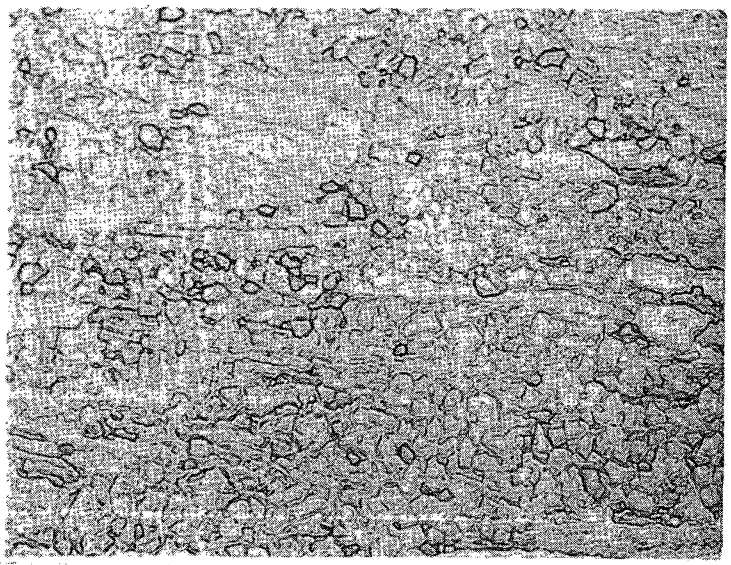
The bottom 2-1/4 feet of the furnace
(Total Height is 7-1/4 feet)

Calibration was performed with the use of three thermocouples lowered through ports in the furnace top to distances of 8 and 27 inches above the furnace hearth. RMI had decided that the billets should be finish forged, at 1775°F, rather than 1800°F. Consequently, a furnace calibration run of



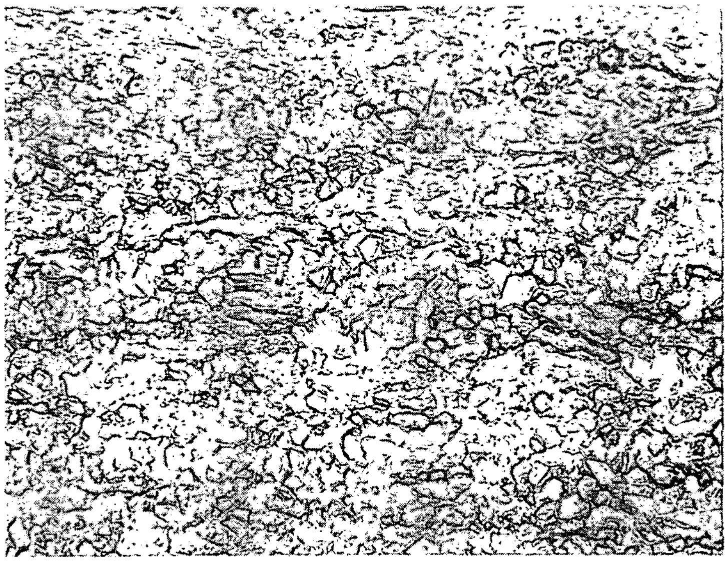
200X FIGURE 17 HF/HNO_3

Appearance of Ti 5Al-2.5Sn ELI Heat 804722 (RMI) in the "as-rolled" condition. Microstructure consists of severely distorted primary alpha.



200X FIGURE 18 HF/HNO_3

Effect on microstructure of 1750°F - 1/2 hr., followed by water quench. Microstructure is still predominantly elongated showing approx. 25% recrystallization to equiaxed, primary alpha.

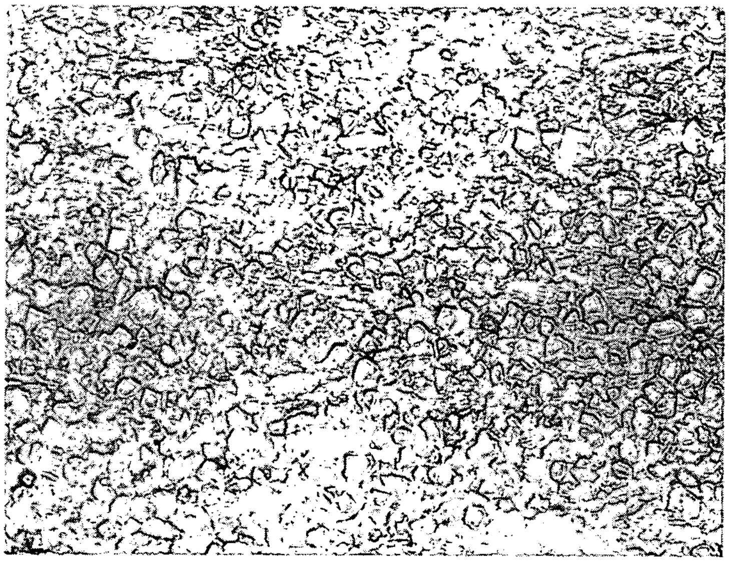


200X FIGURE 19 HF/HNO_3

Effect on microstructure after 1760°F, 1/2 hr., followed by water quench. Microstructure is almost entirely recrystallized with approx. 15% of area still showing effects of rolling.

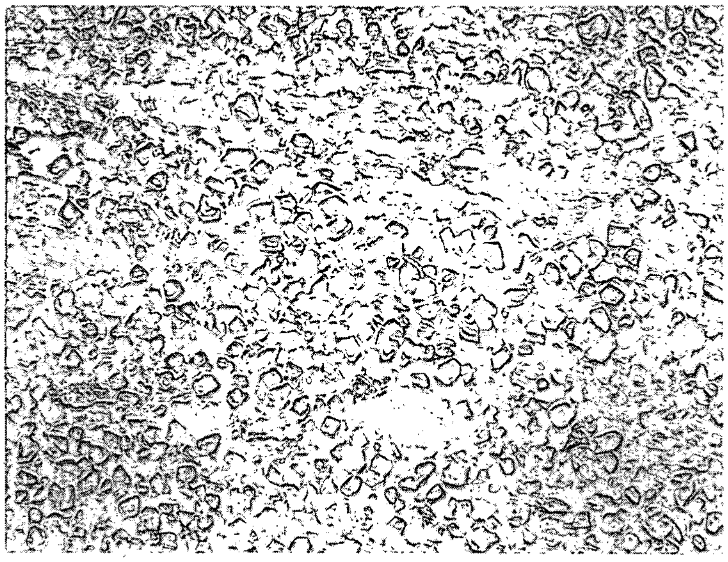
200X FIGURE 20 HF/HNO_3

Effect on microstructure after 1770°F, 1/2 hr., followed by water quench. An additional few percent has recrystallized to equiaxed, primary alpha.



200X FIGURE 21 HF/HNO_3

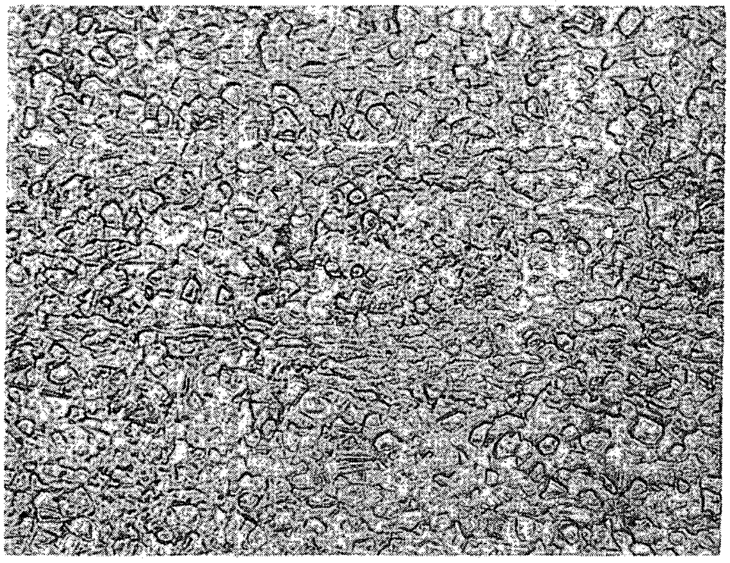
Effect on microstructure after 1780°F, 1/2 hr., followed by water quench. Microstructure is now 100% recrystallized to equiaxed, primary alpha. No evidence of heating above alpha transus is as yet evident.



200X FIGURE 22 HF/HNO_3

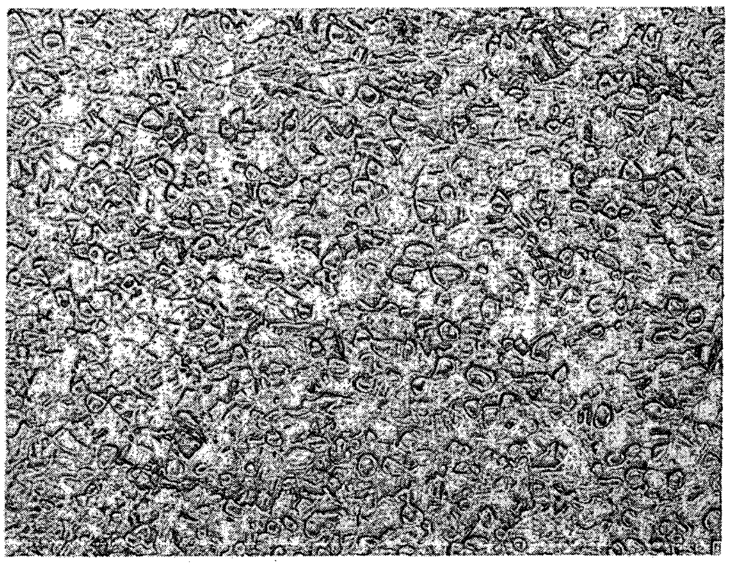
Effect on microstructure after 1790°F, 1/2 hr., followed by water quench. Heavy appearing grain boundaries gives first indication of possible heating above alpha transus.

D



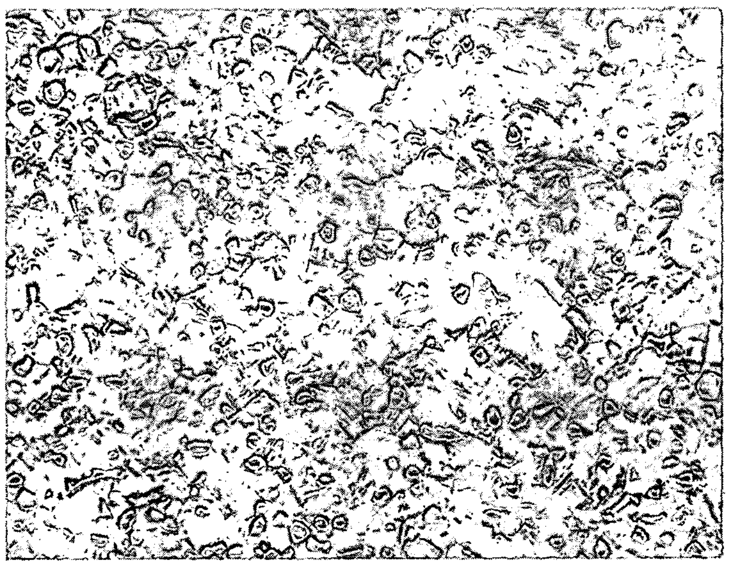
200X FIGURE 23 HF/HNO_3

Effect on microstructure after 1800°F, 1/2 hr., followed by water quench. Fine,dark structure to left of center and in grain boundaries is interpreted to be transformation product, or alpha prime. Alpha transus is, therefore, between 1780 and 1800°F.



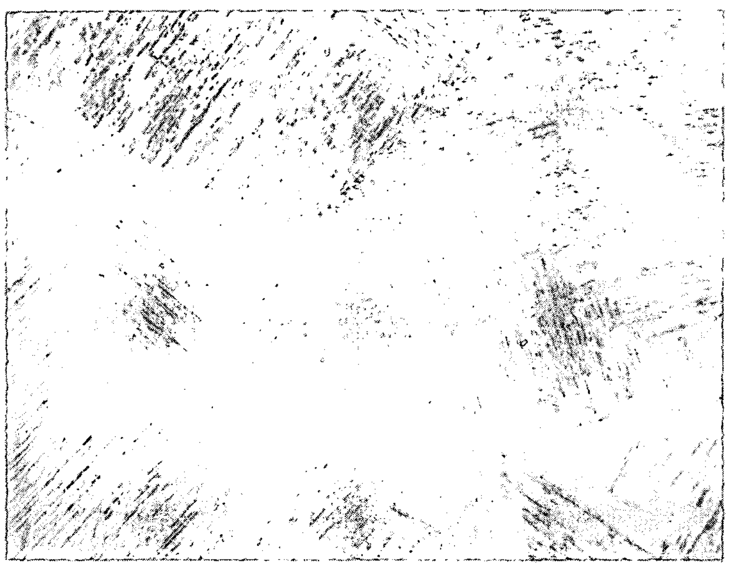
200X FIGURE 24 HF/HNO_3

Effect on microstructure after 1810°F, 1/2 hr., followed by water quench. Darker etching areas, constituting 15-20% of field, are interpreted as alpha prime.



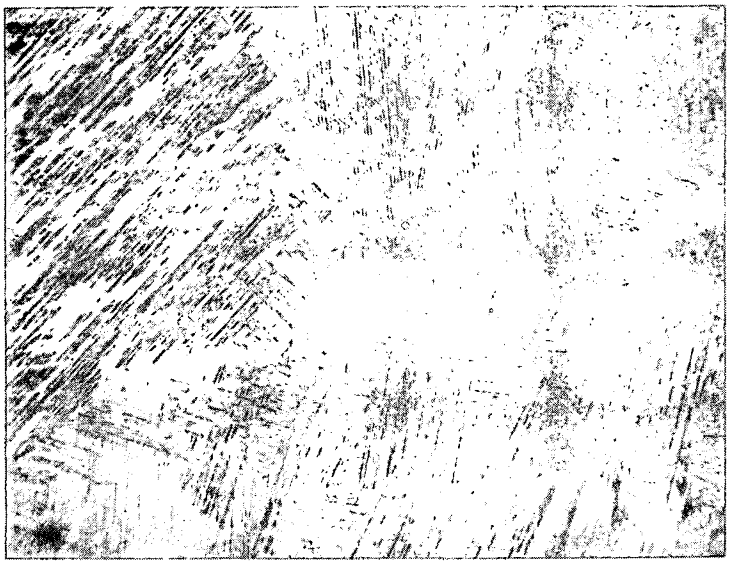
200X FIGURE 25 HF/HNO_3

Effect on microstructure after 1820°F, 1/2 hr., followed by water quench. Equiaxed primary alpha is present as isolated, discontinuous grains. Continuous phase is alpha prime.



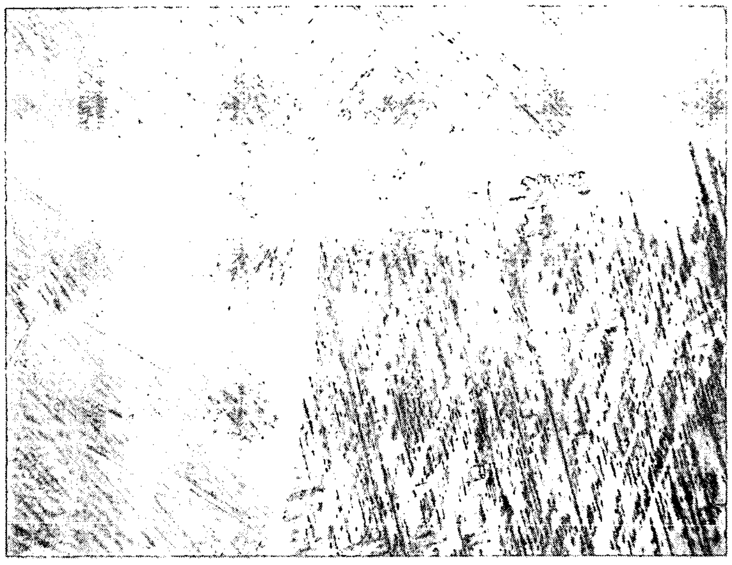
200X FIGURE 26 HF/HNO_3

Effect on microstructure after 1830°F, 1/2 hr., followed by water quench. Microstructure is 100% alpha prime showing beta transus has been exceeded. Transformation product is present in acicular form, in preferred orientation and within prior beta grain outlines.



200X FIGURE 27 HF/HNO_3

Effect on microstructure after 1840°F, 1/2 hr., followed by water quench. Same microstructure as previous figure but slightly heavier etching of alpha prime, possibly due to coarsening of needles.



200X FIGURE 28 HF/HNO_3

Effect on microstructure after 1850°F, 1/2 hr., followed by water quench. Same microstructure as previous figure.

furnace #42 at 1775°F was witnessed. Following adjustment of the calibration potentiometer, three thermocouples were alternatively lowered through the ports at the back of the furnace to the 8 inch hearth elevation, allowed to soak 1-2 minutes and the temperatures read. This process was repeated after raising the thermocouples to the 27 inch elevation. The same procedure was followed at the other nine furnace port locations, and the resultant temperature variation of 46°F was used to establish the maximum finish forging metal temperature, as follows:

Nominal Beta Transus	-	1825°F
Less 1/2 max. transus furnace range	-	5°
Less 1/2 forging furnace range	-	23°
Maximum finish forging temperature: 1797°F		

Since the maximum billet temperature, with the furnace set at 1775°F, will actually be 1792°F (see Enclosure 14), the real safety margin between metal temperature and the adjusted beta transus of 1820°F was 28°F, far in excess of the additional 5° required to accommodate energy dissipation from forging. Results of the 1775°F furnace calibration is shown in Enclosure (14).

The billet was preheated in furnace #43 at 1350°F for eleven hours. The furnace temperature was raised to 2000°F and held for 8 hours. The billet was forged in a 3000 ton press to 16 inch square without incident. A 1950°F calibration run on furnace #43 is included for general information, only, as Enclosure (15).

Following beta forging and a 1/2 hour air cooling, the billet was charged into furnace #42 and allowed to soak at 1775°F for 4 hours. It was then forged to an 11-inch round-cornered-square in a series of seven passes through the press without need for reheating. This was an added forging step over what was used for forging the "T" and "T1" billets earlier and was needed to accommodate the 75°F lower forging temperature; the first two billets were forged directly to 8 inch from 16 inch.

After completion of forging and while the billet was still hot, it was cut into three pieces approximately 4 feet long. These were identified by steel stamping the bottom of the bottom piece "B", the bottom of the middle piece "BA" and the bottom of the top piece "BB". The three pieces were cooled and prepared for "conditioning", as follows:

Surface Ground
Stress Relieved at 1350°F
Sand Blasted
Pickled in nitric/hydrofluoric acid for 1/2 hour.

Following conditioning, the three billets were recharged into furnace #42, set at 1350°F. They were held at that temperature for 13-1/2 hours and then held 3 hours at 1775°F.

During forging to an 8-3/4 semi-octagon, each billet developed cracks along their sides which required extensive grinding to remove. These cracks were, at first, attributed to an improperly radiused forging die; however, increasing radiant heat transfer resulting from the increasing surface area - volume ratio (in addition to the initial lower forging temperature) is considered a more likely reason. From the 16 inch square configuration to the 9 inch square at which cracking was noted, this ratio increased 70%.

Subsequently, the billets were finished to 8-3/8 inch rounds without further incident.

Chemical analyses and tensile tests were performed on two of the billets with the following results:

LOCATION*	C	N	Fe	Al	Mn	Sn	O_2	H_2(ppm)
	CHEMISTRY							
1BB	0.02	.008	.22	5.0	<.01	2.5	.059	68
B	0.01	.008	.17	5.0	<.01	2.5	.064	79

Tensile tests were made on a section of billet which had been forged down from 2 inch to 3/4 inch thick at 1700°F, followed by annealing at 1500°F, 1 hour and air cooled. The following results were obtained:

LOCATION*	UTS (KSI)	TYS (KSI)	% El	% R OF A
1BB	122	111	18	49
B	117	108	21	46

Both the chemistry and the mechanical properties were well within the requirements of ANS-90295B.

At this time, a strike at RMI prevented further processing of these three billets and they were not available for forging.

* 1BB represents the top of the first (or top) billet produced from the original 19 inch square semi finished billet; B represented the bottom of the last (or bottom) billet produced. (See Figure 29.)

RMI BILLET LOCATION

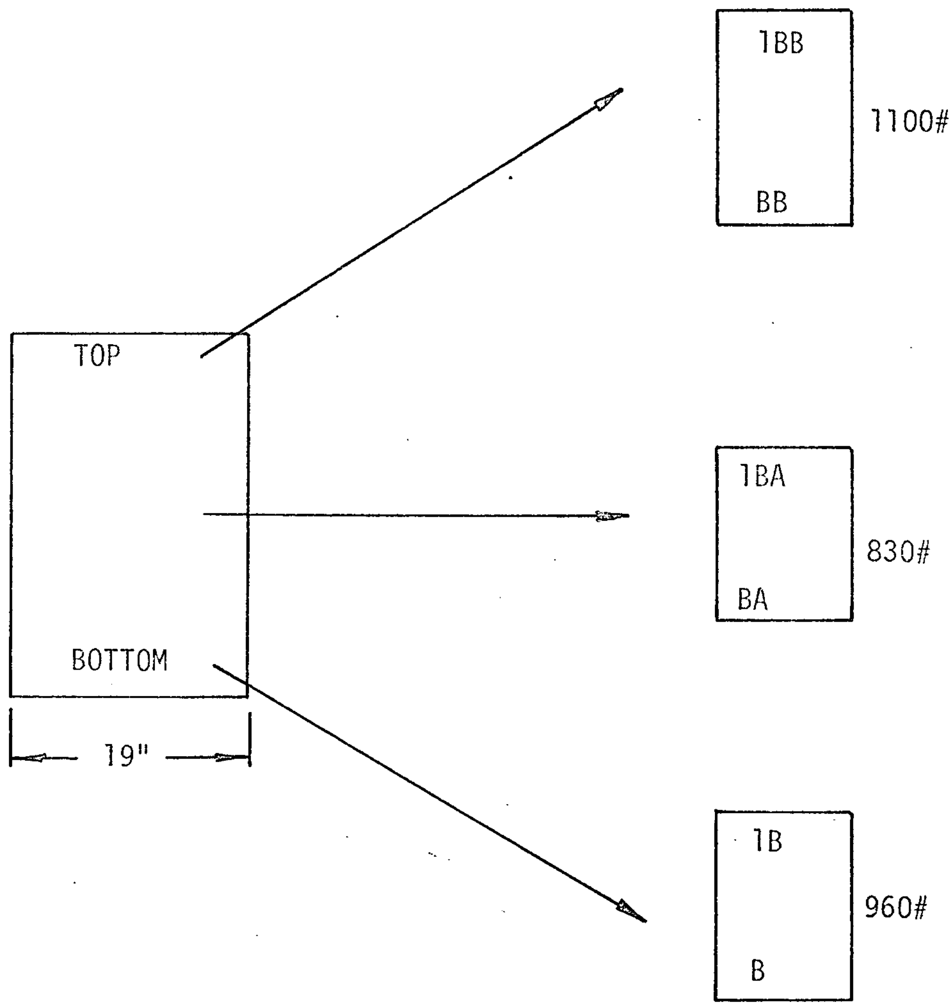


FIGURE 29

V. FORGING PROCUREMENT HISTORY

The purchase orders to Arcturus Manufacturing Company and ANSC participation during forging will be discussed below. A second procurement placed with Carlton Forge Works to produce second stage impeller forgings, P/N 1138575 and second stage rotor forgings, P/N 1138578, was never fully activated and no forgings were produced; the reason for this was the interruption in ANSC titanium procurement by the titanium producers' strike and SNSO refusal to allow use of available TMCA Heat K8930 material.

Purchase Orders N-00554, 00555, 00556, 00557, 00558, and N-01405 were placed calling for production of first and second stage impellers, first and second stage turbine rotors and inducers. The forgings ordered on Purchase Orders N-00554 thru N-00558 were for turbopump components and the forgings ordered on Purchase Order N-01405 were for the 144 specimen material test program outlined in Reference 1. All parts ordered for turbopump application were to be from TMCA supplied material. Both RMI and TMCA material was to be used for the material test program forgings. Forging quantities and serial numbers of each order are shown in Table IV. All parts, with the exception of the inducers, were to be primarily die forged; the inducers were to be open hammer pancake forged.

On ANSC instructions, TMCA shipped the following four billets to Arcturus: billets B, T4, T2 and T, which represented the billet from the bottom of the ingot (B), the next-to-the-bottom billet (T4), and the two billets from the top, T and T2. In addition, one of the two RMI billets, T, was also shipped to Arcturus. The remaining two billets, TMCA billet T3 and RMI billet T1, were shipped to Carlton.

TABLE IV

FORGING ORDERS TO ARCTURUS MANUFACTURING CO. PRIOR TO SNSO STOP ORDER

ANSC P.O.	FORGING PART NO.	FORGING DESCRIPTION	QTY	ANSC SERIAL NO.	BILLET MATERIAL SOURCE
N-00554	1138579-1C	Inducer	5	880001 880002 880003 880007 880009	TMCA
	1138579-2C	Inducer (Second Impeller Insert)	5	880004 880005 880006 880008 880010	TMCA
N-00555	1138578-1E	Second Stage Turbine Rotor	5	880001 880002 880003 880004 880005	TMCA
N-00556	1138577-1D	First Stage Turbine Rotor	5	880001 880002 880003 880004 880005	TMCA
N-00557	1138576-1E	First Stage Impeller	5	880001 880002 880003 880004 880005	TMCA
N-00558	1138575-1D	Second Stage Impeller	5	880001 880002 880003 880004 880005	TMCA
N-01405	1138575-1D	Second Stage Impeller	2	880006 880007	TMCA
	1138578-1E	Second Stage Turbine Rotor	6	880006 880007 880008 880009 880025 880027	TMCA
	1138575-1D	Second Stage Impeller	3	880008 880009 880010	Reactive Metals
	1138578-1E	Second Stage Turbine Rotor	7	880010 880011 880012 880013 880014 880026 880028	Reactive Metals

Subsequently, ANSC was notified by Arcturus that the billets had been received and ANSC personnel were dispatched to review the billet microstructure and the proposed forging practice to be used.

The TMCA B and T4 bars and the RMI T bar were subjected to portable electro polishing and microstructure examinations by Arcturus. Following these checks, a meeting was held to discuss the results.

The microstructures were reviewed and discussed and the microphotos shown in Figures 1 through 14 were made available. A set of these same TMCA microphotos had previously been sent to Arcturus by TMCA and had been examined. Arcturus reiterated that the transformed alpha microstructure would be improved by preliminary cross-forging steps and foresaw no problems. A decision was made to cross-forge <u>all</u> the billet starting stock regardless of billet microstructure or source. Arcturus planned to make a try-out forging of each configuration starting with the smallest forging (2nd stage rotor) and check to see that the as-forged microstructure was fine and equi-axed prior to forging the next bigger part.

In addition, Arcturus' forging procedures, Appendix 4, were reviewed and ANSC comments relayed back to ANSC-QC prior to initiation of actual forging. Subsequently, ANSC was to monitor the forging and acceptance testing of each of the first article (try out) forgings.

The procedures were reviewed and were generally acceptable; areas requiring change were in the latest heat treatment requirement, described in the "B" revision of ANS-90297, and in the chlorine and sulphur contamination limits of the dye penetrant used.

It was suggested by Arcturus that the available TMCA bars be forged first, and separately, from the RMI "T" bar. Arcturus had allocated the required project and materials test forgings such that the small forgings, requiring the least reduction, were to come from the best billet (the "B" billet) and larger forgings incorporating heavy die forging operations were to be forged from billets characterized by mixed or predominantly transformed alpha microstructure. In addition, the most difficult-to-forge part, P/N 1138575, was to be forged from one of the two best billets (the T4 billet). This approach was relayed both to ANSC management and SNSO-C, and telecon concurrence was obtained.

Input weights had been calculated by Arcturus and a complete layout had been prepared in the form of a cut chart, shown as Figure 30. On this figure the parts with "X" above them were the originally designated try-outs, and were generally selected from billets with least favorable microstructure; the single exception was P/N 1138578 try-out (2918 S/N 1) which was made from the top end (best end) of the TMCA "T" billet.

On Figure 30, and subsequent figures relating Arcturus work, the following Arcturus die numbering system was used:

ARCTURUS DIE NO.	ANSC P/N	PART	TRY-OUT S/N
2915	1138575	2nd Stage Impeller	S/N 2*
2916	1138576	1st Stage Impeller	S/N 1
2917	1138577	1st Stage Rotor	S/N 1
2918	1138578	2nd Stage Rotor	S/N 1
X292	1138579-1	Inducer	S/N 1
X293	1138579-2	Impeller Insert	S/N 1

*S/N 2 was assigned because the configuration had been forged and delivered to ANSC once previously for a high speed balance facility mockup.

FIGURE 30

ORIGINAL CUT-CHART PROPOSED BY ARCTURUS (8/16/71)

2918 88#	2918 88#	2918 88#	2916 100#	17# END

OK.

$48\frac{1}{8}$" = 387#

2918 88#	2918 88#	2916 100#	2916 100#	16# END

48" = 388#

2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2916 100#	2917 100#	2918 88#	2916 100#	2917 100# S/N 1

$116\frac{5}{8}$ = 951#

X-29243 105#	X-29243 105#	X-29243 105#	X-29243 105#	X-29243 105#	2917 100#	2917 100#	2915 130#

107" = 866#

2915 130#	2915 130#	2915 130#	2915 130#	2915 130#	2917 100#	2915 130# S/N 2

$109\frac{5}{8}$" = 893#

2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2915 130#	2915 130#	2915 130#

~~334~~

163" = 1330#

The four die forging try-out multiples were cut out, as shown, by removing the proper length of billet, as pre-calculated by Arcturus. This operation was closely watched and the target input weights were met within 0.1 lb. on each occasion. Each multiple cut was immediately identified by die and serial number; in addition, where necessary, the top billet end was reidentified.

The four try-out multiples were then placed in a furnace nearest to the 25000 lb forging hammer; location of the multiples was maintained by marking the furnace door in the same sequence as the cut multiples inside the furnace.

Forging was initiated by soaking all parts at 1775°F for periods of 20 minutes to one hour. The parts were cross-forged, as shown in Appendix 1; cross forging consisted of upsetting the billet input multiple up to 37% into a barrel shaped piece, then drawing, or restoring, the piece back to nearly its original cylindrical shape. These steps were added by Arcturus in order to optimize the billet microstructure prior to die forging. As shown in Appendix 1 and the forging practice travellers prepared by Arcturus, shown in Appendix 2, the 2918 second stage rotor forging received an additional open hammer upsetting step to a 3-1/4 thick pancake prior to die forging until the material had filled the die cavity, as judged by dimensional measurements made on hub diameters, hub lengths and disc thicknesses. Despite numerous incidents of surface cracks and tears, three of the four parts were successfully completed, cut up and examined. In the fourth part, P/N 1138575 try-out, repeated grinding of hub fillet cracking and tearing had reduced the input mass to a degree where insufficient metal remained to fill the die.

Some details of the try-out forging steps are presented in Appendix 3. Three try-outs were sectioned along a diameter in order to examine the resultant microstructure. The microstructure of these three parts, 1138575 S/N 2, 1138576 S/N 1 and 1138578 S/N 1 are presented in Figures 31, 32 and 33 respectively, and provided the first evidence of the extent by which cross and die forging improved the initial billet microstructures.

Following completion of try-out forging and the loss of 1138575 S/N 2, a meeting was held between Arcturus, ANSC and SNSO. It was decided to make a second try-out forging, also from the bottom end of the TMCA T4 bar, but to increase the forging temperature to 1800°F and to limit the forging time (number of blows). Also, the cutting and forging of the TMCA 2918's was planned and it was agreed to cut one slice from between the X-292 and X-293 combined forging in order to conserve material. In addition, SNSO (satisfied that the billet microstructure had indeed been improved) indicated at this time a need for knowing <u>when</u> during forging the structure was converted to forged, equi-axed alpha. Arcturus suggested that an X-292/X-293 set be used for this purpose since this part was to be upset and drawn, only. However, to be convincing, the starting piece had to have transformed alpha microstructure. Therefore, a change in cutting plans was made such that the X-292/X-293 S/N 1 forging was taken from the T2 bar, rather than from the (best) B bar, as originally planned. This change moved one 2916 multiple into the B bar, as shown in the revised cut chart, Figure 34. In addition, a fourth 2915 mutliple (S/N 11) was planned for the RMI bar to make room for the second try-out from the T4 bar, as shown in the revised cut chart with serialized multiples, shown on Figure 35.

E

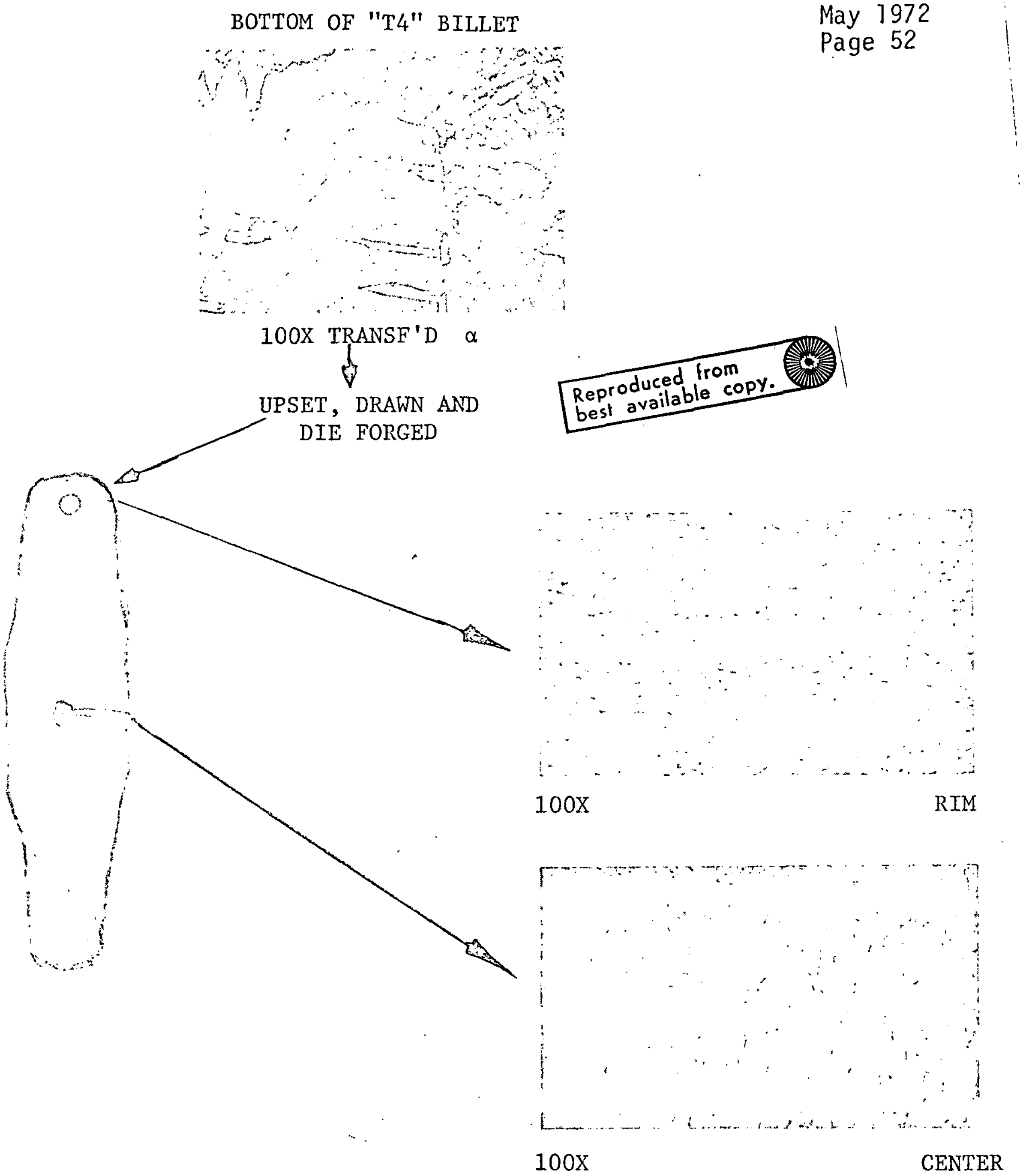
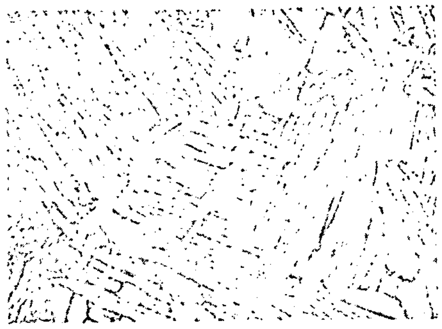


FIGURE 31

P/N 1138575 S/N 2 (FIRST TRYOUT)

2ND IMPELLER, SHOWING EFFECT OF CROSS AND DIE FORGING ON MICROSTRUCTURE OF SEMI-FINISHED PART. HUBS WERE CUT OFF FOR INSPECTION AND TO FACILITATE SECTIONING. FORGED MICROSTRUCTURE IS CONSIDERED EQUIAXED ALPHA WITH DISTORTION IN RIM.

BOTTOM OF "T"



100X TRANSF'D α

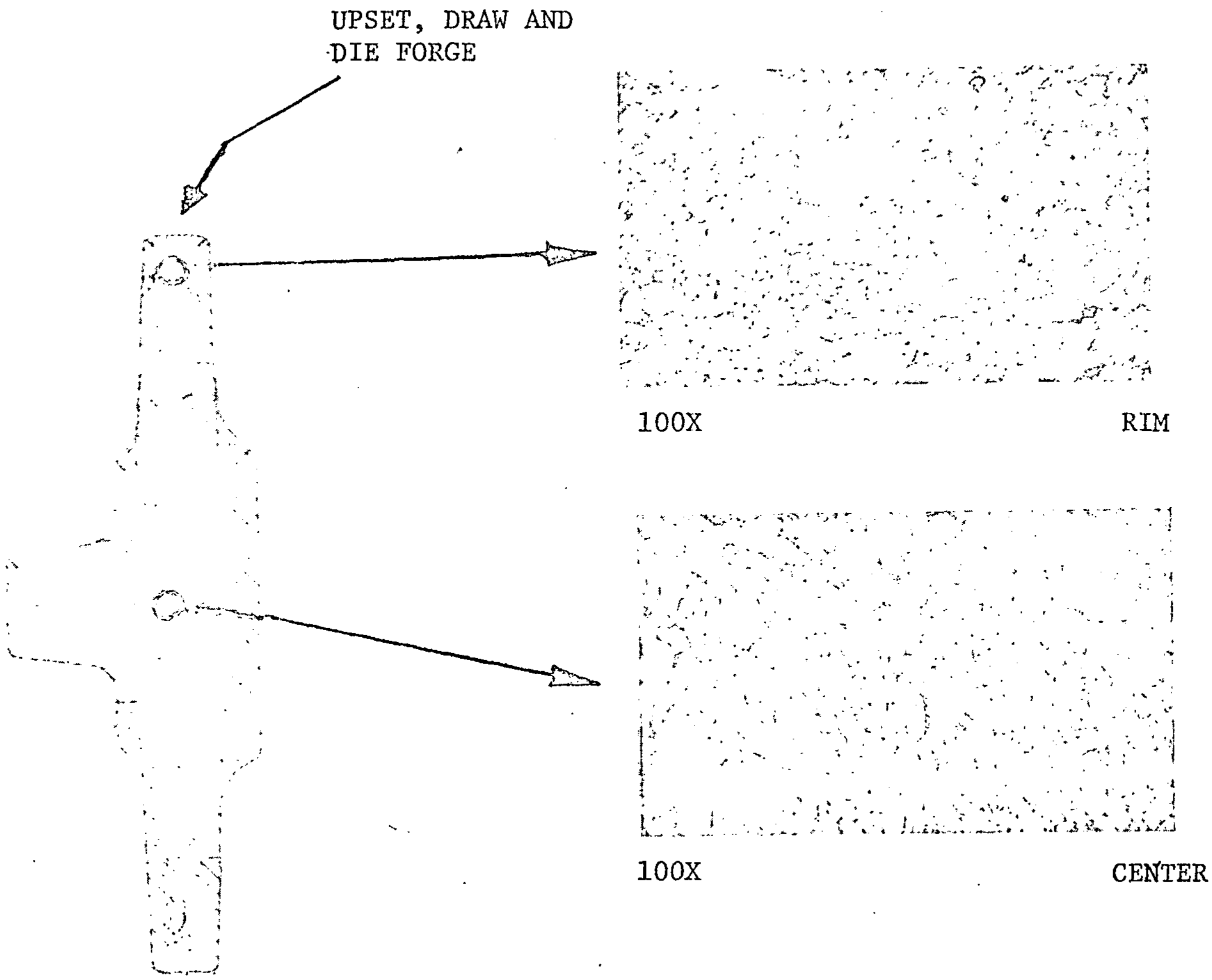


FIGURE 32

P/N 1138576 S/N 1 (FIRST TRY-OUT) 1ST IMPELLER SHOWING EFFECT OF FORGING ON CHANGING MICRO-STRUCTURE TO EQUIAXED.

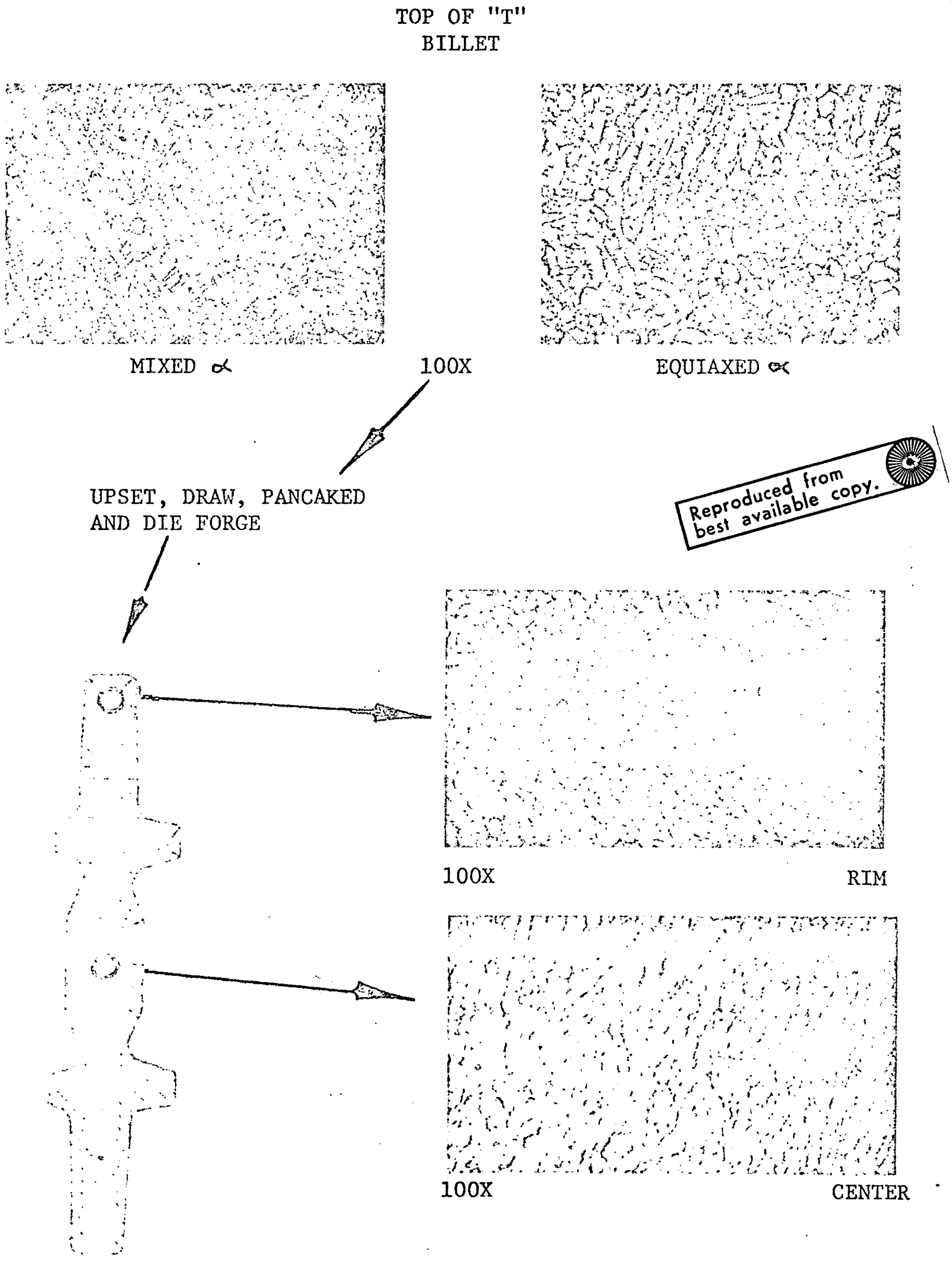


FIGURE 33

P/N 1138578 S/N 1 (FIRST TRY-OUT) 2ND ROTOR SHOWING ACCEPTABLE EQUIAXED MICROSTRUCTURE IN BILLET AND FORGING.

R = Revised 8/

FIGURE 34

1ST. REVISION OF ARCTURUS CUT CHART (NECESSITATED TO ACCOMODATE SECOND 2915 TRY-OUT)

TO — OK

THCA K-2930 SAR T

2918 88# Heat 1	2918 88#	2918 88#	2916 100#	17# END

48 1/8" = 389#

TO — OK

TMCA K-2930 SAR T1

2918 88#	2918 88#	2916 100#	2916 100# S/A 1	16# END

48" = 388#

(R) Interchange to prove out when micro is improved.

TO — OK

THCA K-2930 SAR T2

2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2916 100#	2917 100#	2918 88#	X29243 105#	2917 100# S/A 1

116 5/8" = 951#

These will be OK because B bar is OK. Its logic with 550, interchange per above.

TMCA K-2930 BAR B

2916 100#	X-29243 105#	X-29243 105#	X-29243 105#	X-29243 105#	2917 100#	2917 100#	2915 130#

107" = 866#

TO₂ - min.   TO

THCA K-2930 BAR T4

2915 130#	2915 130#	2915 120#	2915 130#	2915 130#	2917 100#	2915 130# S/N 2

109 5/8" = 893#

alt (R)

RMI 694722 BAR-T

2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2918 88#	2915 130#	2915 130#	2915 130#	2915 130#	15#

163" = 1330#

FIGURE 35

CUT CHART REVISION INCORPORATING CHANGES FROM 1ST FORGING WEEK AND INCLUDING SERIAL NUMBERS.

2915 - 11
2916 - 5
2917 - 5
2918 - 18

A 4930 T — T

2918 88# S/N 1	2918 88# S/N 2	2918 88# S/N 3	2916 100# S/N 3	17# END

OK

48 1/8" = 387#

CA 4930 T1 — TO

2918 88# S/N 5	2918 88# S/N 4	2916 100# S/N 2	2916 100# S/N 1	16# END

48" = 388#

CA 4930 T2

							R		TO
72# Dead End.	2918 88# 10	2918 88# 9	2918 88# 8	2918 88# 7	2918 88# S/N 6	2916 100# S/N 4	X-29243 105# S/N 1	2917 100# S/N 2	2917 100# S/N 1

116 5/8 = 951#

CA 4930 T3

R							
2916 100# S/N 5	X-29243 105# S/N 5	X-29243 105# S/N 4	X-29243 105# S/N 3	X-29243 105# S/N 2	2917 100# S/N 5	2917 100# S/N 4	2915 130# S/N 8

107" = 866#

CA 4930 T4

					TO2	TO
2915 130# S/N 7	2915 130# S/N 6	2915 130# S/N 5	2915 130# S/N 4	2917 100# S/N 3	2915 130# S/N 3	2915 130# S/N 2

109 5/8" = 893#

MI 4722 T

									R		
2918 88# S/N 18	2918 88# S/N 17	2918 88# S/N 16	2918 88# S/N 15	2918 88# S/N 14	2918 88# S/N 13	2918 88# S/N 12	2918 88# S/N 11	2915 130# S/N 12	2915 130# S/N 11	2915 130# S/N 10	2915 130# S/N 9

163" = 1330#

The hubs cut from 1138575 S/N 2 try-out, which had been scrapped, were examined visually and with dye-penetrant; the large hub contained two small cracks up to 0.060 inch long. The presence of these internal cracks, and other associated problems, described in Appendix 3A, confirmed the need for the higher forging temperature decided on earlier.

Arcturus had cut nine 1138578 multiples, all from the T and T2 bars, S/N's 2 through 10, see Figure 35 cut chart. The second 1138575 try-out, S/N 3, had been cut and cross forged already without incident.

Arcturus had decided that in order to facilitate metal flow into hub cavities, the upper portions of the dies for P/N's 1138576, 1138577 and 1138578 should be vented by drilling a 0.10 inch hole from the hub cavity out through the top of the die.

In addition to the 1138578 multiples, three 1138576's had been cut from the T bar, two 1138577's had been cut from the T2 bar and the S/N 1 X-292/X-293 set had been cut from the T2 bar. The remaining TMCA bars were checked and only the B bar and approximately 2/3 of the T4 remained intact.

The successful die-forging of the second 1138575 try-out, S/N 3, was witnessed. The forging steps are described in detail in Appendix 3E. While the part was being made, the forging of the nine 1138578's was watched and no abnormalities were noted.

The microstructure of 1138577 S/N 1 was examined and found to be uniform, fine and equiaxed, as shown in Figure 36. The 1138576, 1138577 and 1138578 try-out slices were macroetched and the remaining halves were subjected to a preliminary ultrasonic inspection with a triple A inspection technique and standard used for the 1138575 S/N 1 high speed balancer part. A 3/4 inch diameter Lithium sulfide crystal with 2-1/4 megacycle signal was used. Both grain flow and ultrasonic test results were satisfactory.

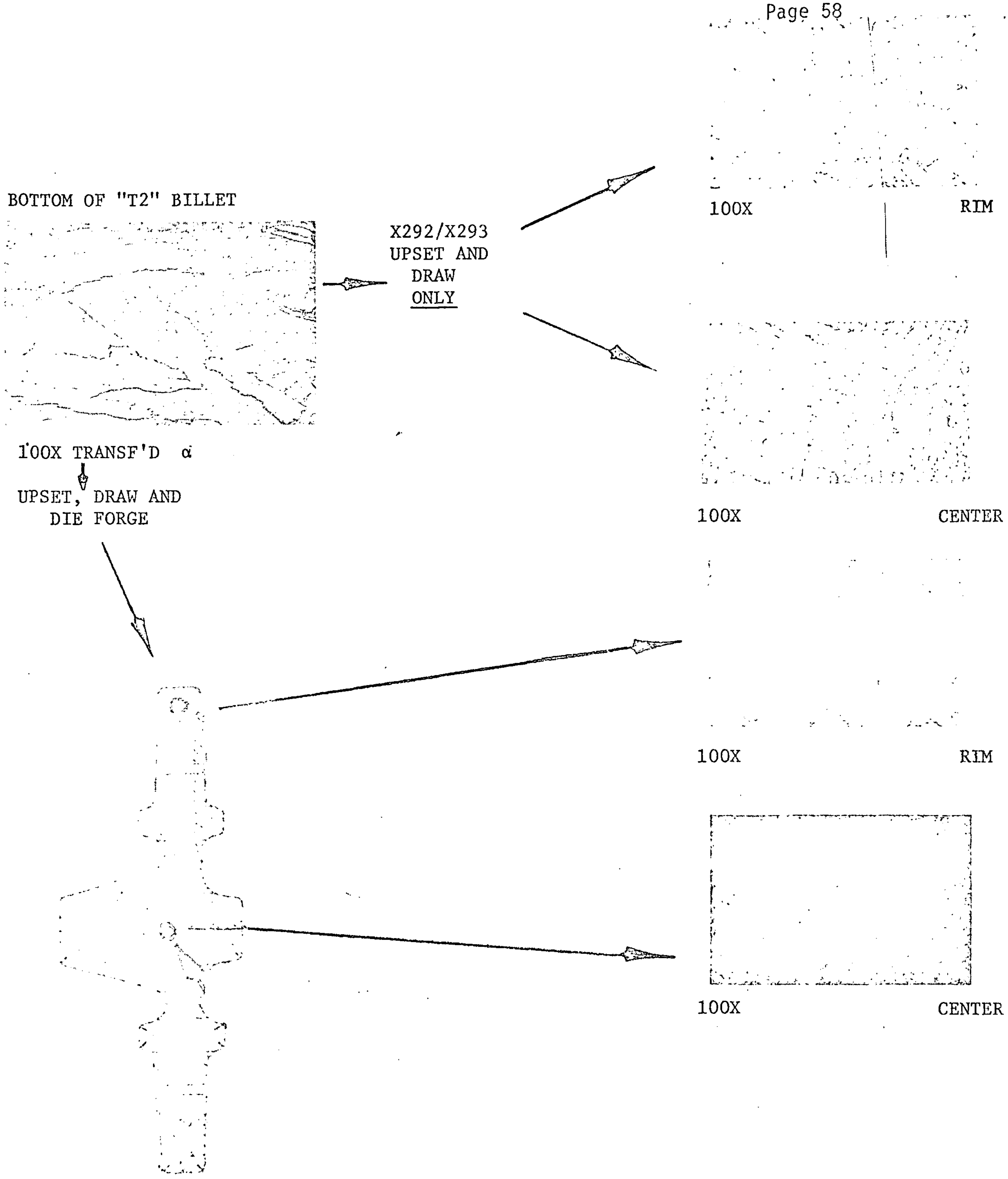


FIGURE 36

P/N 1138577 S/N 1 and P/N 1138579 S/N 1 (FIRST TRY-OUTS) SHOWING TH.
EFFECT OF CROSS-FORGING ON THE DEGREE OF MICROSTRUCTURAL IMPROVEMENT
STRUCTURES ARE CONSIDERED EQUIAXED WITH VARIOUS DEGREES OF DISTORTION

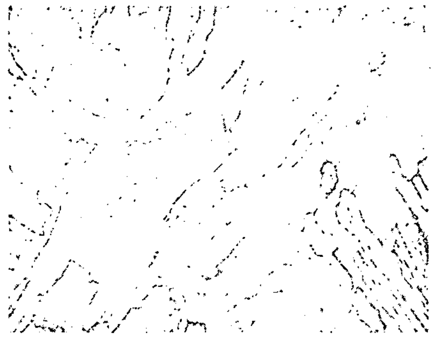
When the 1138575 S/N 3 try-out slice became available, it was examined for microstructure and equiaxed alpha was noted in all forging sections, as shown in Figure 37.

The next forging planned was the pancake forged X-292/X-293 S/N 1 try-out. It was completed just before SNSO instituted their request to stop forging pending a decision as to whether or not the TMCA and RMI billets were suitable for TPA and test forgings.

The X-292/X-293 forging was upset and drawn, only, from a section of the T2 billet in order to determine whether the transformed alpha microstructure was significantly broken down and agglomerated at this stage. Microstructures were examined on the "original cut" plane shown in Figure 38 and a significant microstructural improvement was noted, as shown in the top photos of Figure 36; it should be noted, however, that these inducer forgings were scheduled to be made from the B billet to compensate for the lesser amount of forging work.

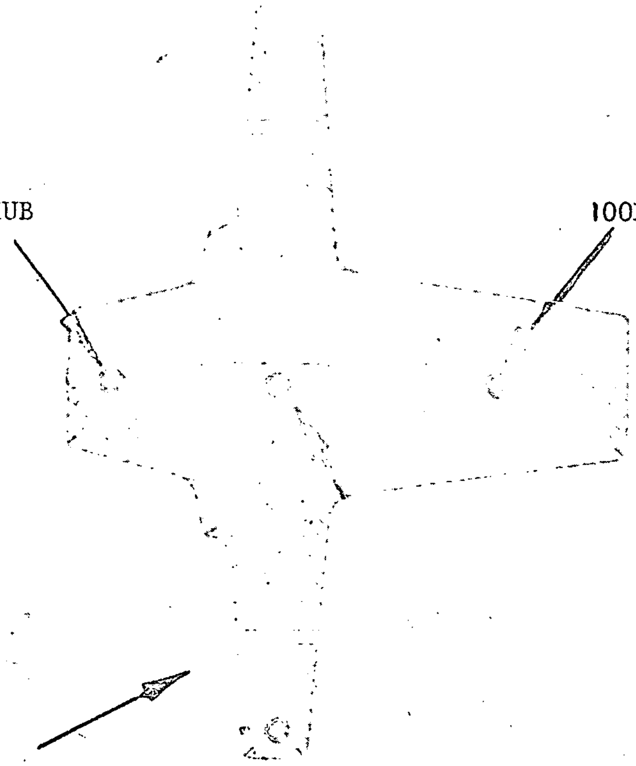
A directive from SNSO-C was received requesting all forging and forging processing at Arcturus be stopped pending resolution of the adequacy of the TMCA material microstructure. Table V presents the forging work scope accomplished at the time of the SNSO stop order. Axial and radial micro, macro, dye penetrant and ultrasonic inspections were to be made available from an upset and drawn forging representing material forged from billet stock with transformed alpha microstructure. It was agreed that the recently completed X-292/X-293 S/N 1 try-out made from the bottom end of the T2 bar would meet SNSO-C requirements. Accordingly, a meeting was arranged to enable SNSO personnel to view for themselves, the results of the tests which SNSO had requested.

BOTTOM OF "T4" BILLET



100X TRANSF'D α

UPSET, DRAW AND DIE FORGE



100X SMALL HUB

100X LARGE HUB

100X RIM

100X CENTER

FIGURE 37

P/N 1138575 S/N 3 (2ND TRY-OUT) 2ND IMPELLER SHOWING UNIFORM, FINE EQUIAXED ALPHA MICROSTRUCTURE COMPARED TO TRANSFORMED ALPHA MICROSTRUCTURE OF STARTING BILLET.

FIGURE 38

PANCAKE FORGING

X292/X293 FROM T2 BILLET

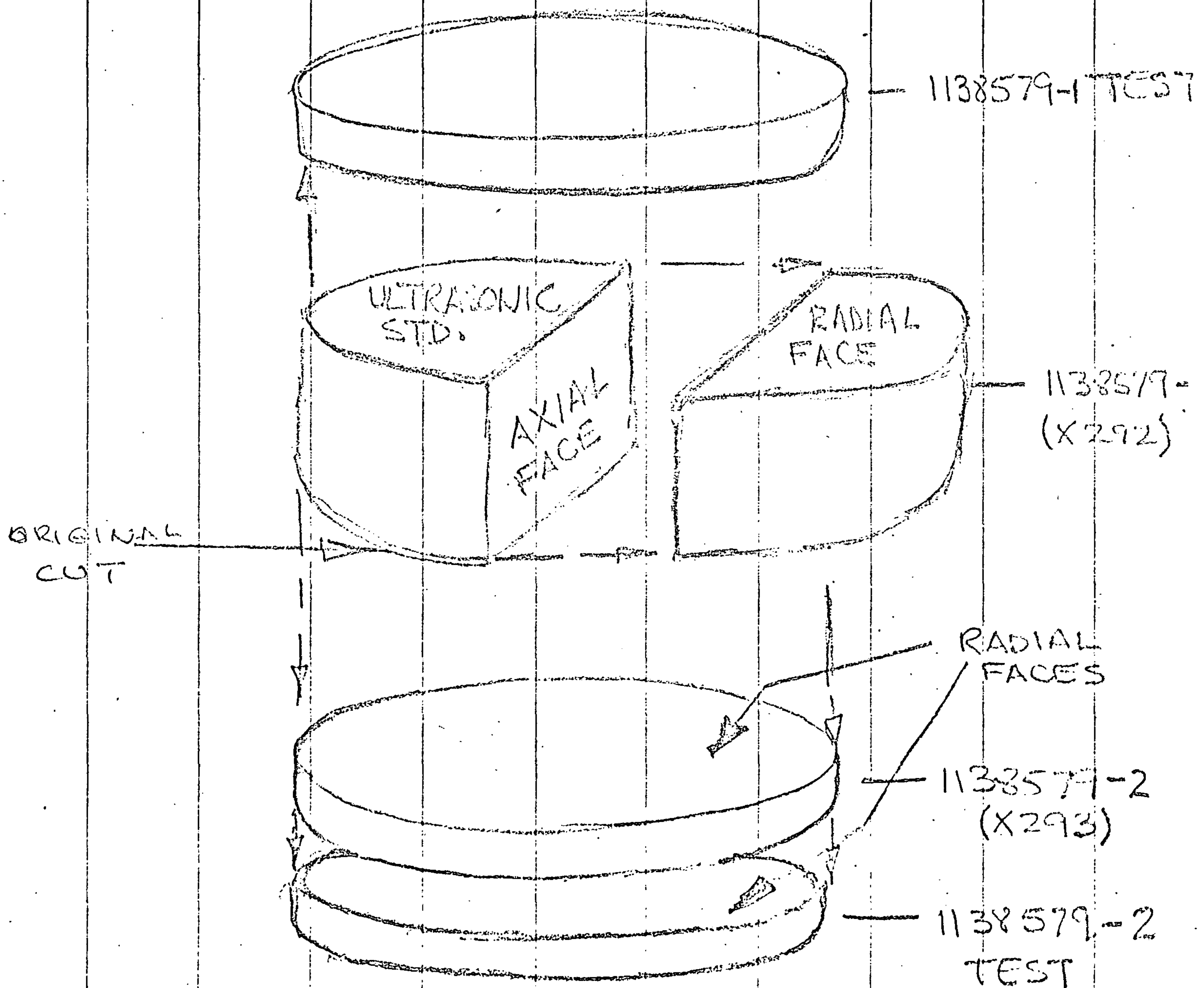


TABLE V

FORGINGS PRODUCED AT TIME OF SNSO STOP ORDER

ANSC P.O.	FORGING PART NO.	ANSC SERIAL NO.
N-00554	1138579-1	* 880001
	1138579-2	* 880004
N-00555	1138578-1	* 880001
		880002
		880003
		880004
N-00556	1138577-1	* 880001
N-00557	1138576-1	* 880001
N-00558	1138575-2	* 880001
		* 880002
N-01405	1138578-1	* 880006
		880007
		880008
		880009
		880025
		880027

*Sectioned Try-out Piece.

The X-292/X-293 try-out forging had been cut into five sections, as shown on Figure 38. One half of the 1138579-1 had been prepared as an ultrasonic standard, containing several flat-bottomed holes and notches to facilitate ultrasonic inspection. All five pieces had been dye-penetrant inspected and found to be defect free. Microstructure examinations were made on the axial face of 1138579-1 and compared with previously made micros of the radial face; the microstructures were similar in both directions and consisted primarily of worked alpha, exhibiting various amounts of distortion, see upper right hand pictures of Figure 36.

Ultrasonic inspections using contact scanning of all pieces indicated that the material met the AAA flaw size requirement.

In preparation for the meeting with the SNSO-C and SNSO-W people, four displays were prepared, similar to Figures 32, 33, 36 and 37, which were planned for use in describing the microstructures in both billet and forging form.

Subsequently, a meeting was held with Arcturus, SNSO and ANSC. A brief material history covering both titanium heats was provided by ANSC. Arcturus then described company philosophy and experiences with titanium forging, which form the basis for the purchase order requirement that the titanium billets not be finish forged above the beta transus temperature. Arcturus indicated that cross forging of the material had converted the billet microstructure to a sufficiently equiaxed form to render the material forgeable. In addition, it was implied that cross forging the multiples merely introduced a forging step which would have been unnecessary had the billets been finish forged at the proper temperature but which Arcturus would include in all subsequent ANSC titanium orders for rotating component forgings.

A detailed review was given, using the four visual displays. The SNSO personnel indicated agreement that a definite improvement in material microstructure was achieved. This fact, however, apparently did not dispel their apprehension concerning the reproducibility of the starting billet material and any possible effects of the prior transformed alpha; the fact that billets are always processed above the beta transus temperature at some stage during their manufacture made no difference, nor did many other arguments mounted by both ANSC and Arcturus.

During subsequent meetings, an SNSO "proposition" was drafted which included the following items:

1. Use the TMCA B bar and the RMI T bar to make three sets of TPA forgings to satisfy S/N 1 requirements.
2. Continue hold on Carlton forgings and other Arcturus forgings.
3. Reactivate remainder of RMI heat with added controls to preclude finish forging above beta transus. Distribute this material to Arcturus and Carlton for making S/N 2 TPA parts and materials test program parts.
4. Conduct interim tests to qualify S/N 1 TPA parts use.
5. Carry along one-half of existing try-out forgings with S/N 1 parts to be processed.
6. Order more billets for balance of program.

A check was made to see whether three sets of forgings could be made from the already cut up B and T bars. As shown in Figure 39, three sets of parts could be made in this manner, in addition to one 2918 try-out from the RMI bar. However, provision had to be made for try-out forgings representative of the 2915 and 2916 RMI forgings.

The stop order imposed by SNSO was fraught with confusion; for some time, conflicting directions flowed between Sacramento and Cleveland, in both directions. An ANSC proposal to keep try-out forgings and production forgings together (from same billet) was rejected after several days because it would have required use of other than the customer approved billets. However, the SNSO "proposition", which later appeared in the form of a written directive, had failed to account for the need for try-out forgings from the RMI heat; therefore, approval was obtained to use some of the non-approved RMI T1 billet for this purpose. This approval resulted in transferring the RMI T1 billet from Carlton Forge Works (the second forger) to Arcturus.

In order to implement the SNSO stop order, a complete review was made of the accomplished work scope, the new forging quantity requirements and the remaining available material (which was in cut multiple form except for the RMI T1 bar). This review resulted in:

(a) Revising the turbopump program forging requirements from four to three finished forgings for each machined configuration.

(b) Transferring (and in some cases recutting) several forging input billets to other purchase orders.

(c) Issuing ANSC Inspection Reports against all forged material (which was not completely processed through acceptance) requiring shipment to ANSC.

F

116 5/8 = 951 #

Visual exam 9/1 (micro)

TMCA X-F930 BAR B

2916 150# S/N 5	X-29243 105 # S/N 5	X-29243 105 # S/N 4	X-29243 105 # S/N 3	X-29243 105 # S/N 2	2917 100 # S/N 5	2917 100 # S/N 4	2915 130 # S/N 8

107" = 866 #

TMCA K-F930 BAR T4

					TO2	TO
2915 130 # S/N 7	2915 130 # S/N 6	2915 130 # S/N 5	2915 130 # S/N 4	2917 100 # S/N 3	2915 130 # S/N 3	2915 130# S/N 2

109 5/8" = 893 #

Visual exam 9/1

RMI 804722 BAR-T

2918 88 # S/N 18	2918 88 # S/N 17	2918 88 # S/N 16	2918 88 # S/N 15	2918 88 # S/N 14	2918 88 # S/N 13	2918 88 # S/N 12	2918 88. # S/N 11	2915 130 # S/N 12	2915 130 # S/N 11	2915 130 # S/N 10	2915 130 # S/N 9

163" = 1330 #

TMCA ...-F930 BAR B (... CUTTING)

2916 100 lbs S/N 5	X-29243 105 lbs S/N 5	X-29243 105 lbs S/N 4	X-29243 105 lbs S/N 3	2917 100 lbs S/N 6	2917 100 lbs S/N 5	2917 100 lbs S/N 4	2915 130 lbs S/N 8

change

change

RMI 804722 BAR-T (... CUTTING)

2918 88 lbs S/N 18	2918 88 lbs S/N 17	2918 88 lbs S/N 16	2918 88 lbs S/N 15	2918 88 lbs S/N 14	2918 88 lbs S/N 13	2918 88 lbs S/N 12	2918 88 lbs S/N 11	2915 130 lbs S/N 12	2915 130 lbs S/N 11	2916 100 lbs S/N 6	2916 100 lbs S/N 7

Not needed; Hold

Revised 9/1 after Shieb meeting

Makes 3 sets for S/N 1 TPA from TMCA "B" and RMI "T".

FIGURE 39

2ND REVISION OF ARCTURUS CUT CHART INCORPORATING SNSO DIRECTIVES.

Table VI presents the status and disposition of all cut and forged material at Arcturus following the SNSO stop order.

The final approved cut chart, covering three sets of forgings for the turbopump program, some forgings for the interim materials test program and sufficient try-out forgings to assure proper forging practice would continue to be used, is shown in Figure 40. This cut chart (along with the ANSC Inspection Reports and verbal instructions) was used for expeditiously restarting forging production at Arcturus without the customary formal changes to purchase orders. Multiple iterations also were required before the interim materials test plan, shown in Table VII, was agreed upon. This scheme provided for some static and cyclic test data from each rotor configuration, with the test material to be representative of both TMCA and RMI billet material.

Resumption of forging of the TPA and test parts was delayed for some time, both by ANSC's customer-caused interruption as well as by an extended plant absence of a key Arcturus personnel. When forging was resumed, Arcturus was directed to perform forging at a temperature suitable to all the TPA configurations, viz, 1765-1800°F. The revised work scope (reference Figure 40) is presented in terms of ANSC part and serial numbers in Table VIII.

Upon resumption of work, the three sets of TPA parts were forged without incident. Vacuum heat treating and routine inspections were performed in accordance with specification requirements, but ultrasonic inspection, including C-scan inspection, was performed by an NDT vendor with the requisite equipment. The ultrasonic test results (contained in Section VI of this report) formed the basis for allocating the forgings as shown in Table IX.

TABLE VI

MATERIAL STATUS AND DISPOSITION FOLLOWING SNSO STOP ORDER

ANSC P.O.	ANSC PART NO.	ANSC S/N	ARCTURUS DIE NO.	ARCTURUS S/N	BAR	FORM ON 9-14-71	DISPOSITION
N-00554	1138579-1 & -2	880001	X-292/293	1	TMCA-T2	Forged/Sectioned	Continue Processing
	"	880002	"	2	TMCA-B	Cut Billet	Redirect to 1138577-1, S/N 880006 (Ref IR 512358)
	"	880003	"	3	TMCA-B	Cut Billet	Forge
	"	880004	"	4	TMCA-B	Cut Billet	Forge
	"	880005	"	5	TMCA-B	Cut Billet	Forge
N-00555	1138578-1	880001	2918	1	TMCA-T	Forged/Sectioned	Return to ANSC (Ref IR 512359)
		880002	2918	2	TMCA-T	Forged	Return to ANSC (Ref IR 512359)
		880003	2918	3	TMCA-T	Forged	Return to ANSC (Ref IR 512359)
		880004	2918	4	TMCA-T1	Forged	Return to ANSC (Ref IR 512359)
		880005	2918	11	RMI-T	Cut Billet	Forge
N-00556	1138577-1	880001	2917	1	TMCA-T2	Forged/Sectioned	Continue Processing
		880002	2917	2	TMCA-T2	Cut Billet	Return to ANSC (Ref IR 512360)
		880003	2917	3	TMCA-T4	Cut Billet	Return to ANSC (Ref IR 512360)
		880004	2917	4	TMCA-B	Cut Billet	Forge
		880005	2917	5	TMCA-B	Cut Billet	Forge
N-00557	1138576-1	880001	2916	1	TMCA-T1	Forged/Sectioned	Continue Processing
		880002	2916	2	TMCA-T1	Cut Billet	Return to ANSC (Ref IR 512361)
		880003	2916	3	TMCA-T	Cut Billet	Return to ANSC (Ref IR 512361)
		880004	2916	4	TMCA-T2	Cut Billet	Return to ANSC (Ref IR 512361)
		880005	2916	5	TMCA-B	Cut Billet	Forge

TABLE VI (Continued)

ANSC P.O.	ANSC PART NO.	ANSC S/N	ARCTURUS DIE NO.	ARCTURUS S/N	BAR	FORM ON 9-14-71	DISPOSITION
N-00558	1138575-2	880001	2915	2	TMCA-T4	Forged/Sectioned	Scrap - Replace with S/N 880018
		880002	2915	3	TMCA-T4	Forged/Sectioned	Continue Processing
		880003	2915	4	TMCA-T4	Cut Billet	Return to ANSC (Ref IR 512362)
		880004	2915	5	TMCA-T4	Cut Billet	Return to ANSC (Ref IR 512362)
		880005	2915	8	TMCA-B	Cut Billet	Forge
N-01405	1138575-2	880006	2915	6	TMCA-T4	Cut Billet	Return to ANSC (Ref IR 503988)
		880007	2915	7	TMCA-T4	Cut Billet	Return to ANSC (Ref IR 503988)
		880008	2915	9	RMI-T	Cut Billet	Redirect to 1138576-1 S/N 880006 (Ref IR 503990)
		880009	2915	10	RMI-T	Cut Billet	" " " "
		880010	2915	11	RMI-T	Cut Billet	Transfer to P.O. N-00558 (Ref IR 503990)
	1138578-1	880006	2918	5	TMCA-T1	Forged	Return to ANSC (Ref IR 503989)
		880007	2918	6	TMCA-T2	Forged	Return to ANSC (Ref IR 503989)
		880008	2918	7	TMCA-T2	Forged	Return to ANSC (Ref IR 503989)
		880009	2918	8	TMCA-T2	Forged	Return to ANSC (Ref IR 503989)
		880010	2918	12	RMI-T	Cut Billet	Transfer to N-00555 & Forge (Ref IR 503991)
		880011	2918	13	RMI-T	Cut Billet	" " " "
		880012	2918	14	RMI-T	Cut Billet	" " " "
		880013	2918	15	RMI-T	Cut Billet	" " " "
		880014	2918	16	RMI-T	Cut Billet	Return to ANSC (Ref IR 503991)
		880025	2918	9	TMCA-T2	Forged	Return to ANSC (Ref IR 503989)
		880026	2918	17	RMI-T	Cut Billet	Return to ANSC (Ref IR 503991)
		880027	2918	10	TMCA-T2	Forged	Return to ANSC (Ref IR 503989)
		880028	2918	18	RMI-T	Cut Billet	Return to ANSC (Ref IR 503991)

FIGURE 40
TITANIUM CUT CHART
FOR
REVISED WORK SCOPE OF 9-23-71

FORGED-CONTINUE TO PROCESS

	TO	TO
TMCA Bar-T2	2917 100 Lb. S/N 1	X-292/3 105 Lb. S/N 1

	TO
TMCA Bar-T1	2916 100 Lb. S/N 1

	TO
TMCA Bar-T4	2915 130 Lb. S/N 3

HAS BEEN CUT-TO BE FORGED & PROCESSING COMPLETED

TMCA Bar-B	2916 100 Lb. S/N 5	X-292/3 105 Lb. S/N 5	X-292/3 105 Lb. S/N 4	X-292/3 105 Lb. S/N 3	2917 100 Lb. S/N 5	2917 100 Lb. S/N 4	2915 130 Lb. S/N 8

	TO						
RMI Bar-T	2918 88 Lb. S/N 15	2918 88 Lb. S/N 14	2918 88 Lb. S/N 13	2918 88 Lb. S/N 12	2918 88 Lb. S/N 11	2915 130 Lb. S/N 12	2915 130 Lb. S/N 11

TO BE RE-CUT TO NEW INPUT SIZES, FORGED & PROCESSING COMPLETED

	WAS			TO BE
TMCA Bar-B	X-292/3 105 Lb. S/N 2	⟹	TMCA Bar-B	2917 100 Lb. S/N 6
RMI Bar-T	2915 130 Lb. S/N 10	⟹	RMI Bar-T	2916 100 Lb. S/N 6
RMI Bar-T	2915 130 Lb. S/N 9	⟹	RMI Bar-T	2916 100 Lb. S/N 7

TO BE CUT, FORGED & PROCESSING COMPLETED

	TO	TO	
RMI Bar-T1	2915 130 Lb. S/N 13	2916 100 Lb. S/N 8	Dead End

TABLE VII

Ti 5Al-2.5 Sn ELI DIE FORGING

INTERIM MATERIALS TEST PROGRAM

	No. of Semi Ring	Arcturus S/N	70 ± 10°F/100 PSI GH_2			-160 ± 10°F/1200 PSI GH_2			-423 $\pm^{15°}_{0°}$F LH_2		
			K_{Ic}	K_i/K_{IC} = 0.5	SPARE (*)	K_{Ic}	K_i/K_{IC} = 0.5	SPARE (*)	K_{Ic}	K_i/K_{IC} = 0.5	SPARE (*)
1138575 Ring	2	8, 12	1	1	1				1	1	1
1138576 Ring	2	5, 6				1	1	1	1	1	1
1138577 Ring	1	4				1	1	1			
1138578 Ring	1	11	1	1	1						
1138578 Center	1	11 (Forging)	1	1	1						
1138579 Slice	3	3,4,5 (Slices)							1	1	1

TOTAL TESTS - 16 (PLUS 8 SPARES)

*Spares are to be used to replace spurious or outlier test results, only.

TABLE VIII

REVISED WORK SCOPE

ANSC P/N	ARCTURUS DIE NO.	ANSC S/N	ARCTURUS S/N	BILLET
1138575-2E	2915	880002	3	*TMCA-T4
		880005	8	TMCA-B
		880010	11	RMI-T
		880018	12	RMI-T
		880019	13	**RMI-T1
1138575-1E	2916	880001	1	*TMCA-T1
		880005	5	TMCA-B
		880006	7	RMI-T
		880007	6	RMI-T
		880008	8	**RMI-T1
1138577-1D	2917	880001	1	*TMCA-T2
		880004	4	TMCA-B
		880005	5	TMCA-B
		880006	6	TMCA-B
1138578-1E	2918	880005	11	RMI-T
		880010	12	RMI-T
		880011	13	RMI-T
		880012	14	RMI-T
		880013	15	**RMI-T
1138579-1 & -2C	X292/X293	880001	1	*TMCA-T2
		880003	3	TMCA-B
		880004	4	TMCA-B
		880005	5	TMCA-B

*Tryout Forging for TMCA Material
**Tryout Forging for RMI Material

TABLE IX

FORGING ALLOCATIONS

FORGING P/N	FORGING S/N	ALLOCATION
1138575-2E	880018	Machine second stage impeller
	880005	Machine second stage impeller
	880010	Spare
1138576-1E	880006	Machine first stage impeller
	880005	Machine first stage impeller
	880007	Spare
1138577-1D	880004	Machine first stage turbine rotor
	880005	Machine first stage turbine rotor
	880006	Spare
1138578-1E	880011	Machine second stage turbine rotor
	880010	Machine second stage turbine rotor
	880012	Spare
	880005	For interim materials evaluation tests
1138579-1C	880003	Machine inducer
	880005	Machine inducer
	880004	Spare
1138579-2C	880003	Impeller Insert - Not required due to design change
	880005	Impeller Insert - Not required due to design change
	880004	Impeller Insert - Not required due to design change

VI. NON DESTRUCTIVE TESTING OF BILLETS AND FORGINGS

Established penetrant, ultrasonic and x-ray techniques and standards were employed for NDT inspection of both billets and forgings. Table X lists the techniques, specifications and accept/reject criteria used.

Billet Inspection - The penetrant inspection was of sufficient sensitivity to detect the objectionable defects noted in Table XI. The problem here, though, is not inspection sensitivity but one of finding penetrant solutions with sulfur and chlorides within the prescribed limits. Requirements were relaxed for new purchase orders; however, the relaxed quantities are available only in especially ordered solutions.

Nearly identical ultrasonic scanning techniques were employed by RMI and TMCA. The procedure is summarized in Enclosure 16. The inspection standards were fabricated of the same billet material as that being tested so the conditions in the reference standard closely resembled those in the billet. The configuration of the standard is shown in Enclosure 8.

The billets were lathe turned to provide a suitable surface for evaluation to the 3/64 inch diameter flat bottom hole (FBH) acceptance level. An inspection frequency of 5 MHz is dictated by the 3/64 FBH quality level. Metal noise can be reduced, in some measure, by lowering the frequency to 2.25 MHz or even 1 MHz at the sacrifice of sensitivity. The lower frequency beam may not see the grain condition that causes it to scatter at higher frequencies, but it is just as likely to miss real flaws.

TABLE

NDT of 5 Al - 2.5Sn Titanium Alloy

Material	Technique	Specification	Flaw - Type
Sponge	X-Ray	ANS-20296 MIL-STD-453	Discrete contaminants.
Billet	Penetrant	ANS-90295A MIL-I-6866, Type I, Method C ANS-9032-1	Cracks & porosity open to surface. Not more than one indication $\geq$ 1/64-inch permitted.
Billet	Ultrasonic	ANS-90295A MIL-I-8950 (Control only)	Internal cracks, porosity, pipe & inclusions. (1) Any single indication $\geq$ 3/64-inch when compared to 3/64 FBH in reference standard. (2) Loss in back-reflection $>$50% of full-screen saturation.
Forgings	Penetrant	ANS-90297B MIL-I-6866, Type I, Method A ANS-9032-1	Cracks & porosity open to surface. Not more than one indication $\geq$ 1/64-inch permitted.
Forgings	Ultrasonic	ANS-90297B MIL-I-8950B With C-Scan	Internal cracks, porosity & inclusions. Accept/Reject criteria of *Class AAA of MIL-I-8950B.
Forgings	X-ray	ANS-90297B MIL-STD-453	Internal cracks, porosity and inclusions.

*Single indication, $>$ 1/64-in., (when compared to response from a 1/64-in. FBH), multiple indications, $>$10% of 3/64-in. FBH & centers $<$ 1-in.; Stringers, $>$10% of 3/64-in. FBH any length; Noise$>$5% of 3/64-in. FBH; Penetration, Loss of BR $>$20% of full screen saturation.

TABLE XI

VARIATIONS FROM SPECIFIED PENETRANT INSPECTION REQUIREMENTS

5 Al - 2.5 Sn Titanium Alloy Billets

		DISCREPANCY		DISPOSITION
Billets RMI-X21 & 22	(1)	Type II - Visible dye penetrant used, instead of Type I - Fluorescent. Hence, penetrant exceeded 50 ppm each sulfur and chlorides restricted by ANS-90295A.	(1)	Billets washed in solution of HF - HNO_3
	(2)	Ends of billets not penetrant inspected.	(2)	Accepted, based on macroetch results of billet ends.
	(3)	Bar T had one indication 5/8-in. long x 1/8-in. deep and one indication 3/8-in. long x 1/8-in. deep.	(3)	Indications removed.
Billets TMCA (All)	(1)	Penetrant procedure not performed as prescribed by ANS-90295A. Length and depth of indications not noted.	(1)	Accepted. Indications removed.
	(2)	Penetrant solutions exceeded 50 ppm sulfur and chlorides.	(2)	Accepted.

There were no rejectable indications disclosed by ultrasonic examination of the billets. Penetration problems, due to a high metal-noise encountered in the TMCA billets, prevented critical evaluation. Noise in instances exceeded 100% of the 3/64-in. dia. FBH reference (80% of full screen amplitude). A level of 25% and 50% noise was prevelant in the two RMI billets. This response was within the level anticipated. The grain conditions responsible for the high noise-level are discussed in the metallurgical section of this report. In general, both suppliers overestimated forging temperatures which resulted in variations of microstructure. Variations within each billet and between billets were quite apparent in the ultrasonic test results.

<u>Forging Inspection</u> - The finished forgings were subjected to penetrant, ultrasonic and x-ray inspection. There were no rejectable indications disclosed by penetrant inspection.

The forgings were examined ultrasonically using an immersion, pulse-echo technique except a C-scan recorder was added. This recording technique provides a cross-sectional map of the inspection and allows detection of subtle defects by permitting comparison of a suspect region with its surroundings. Ultrasonic scanning procedures are contained in Enclosure 17. Testing was performed by Sonic Testing and Engineering, Inc., Paramount, California.

Half-section and full-section forging standards were fabricated to represent each forging configuration and billet heat of material under evaluation. The flat-bottomed reference holes for longitudinal inspection were of 1/64, 3/64 and 5/64-in. dia. drilled 0.150-in. deep. Shear wave reference holes were of the same diameters drilled at a 45° angle to a depth of 0.250-in.

Distance Amplitude Curve (DAC) calibration blocks with 3/64 FBHs were used to establish DAC curves for each forging. The blocks were fabricated of 6 Al-4V titanium alloy. The DAC curves were adjusted for differences in attenuation between the reference standards and calibration blocks. Actually, the difference was negligible, from 0 in some parts to a maximum of 4 db in others.

The procedural steps for ultrasonic inspection of each forging, in general, were as follows:

(a) A primary response was established as the maximum response from the 3/64 FBH in the forging standard, adjusted on the Cathode Ray Tube (CRT) screen so that response from the 1/64 FBH was approximately 20% of the 3/64 FBH.

(b) The standard was removed. A DAC curve, adjusted to the height of the primary response and covering the full-thickness range of the forging under test, was established on the CRT screen.

(c) The alarm was gated at 10% of the 3/64 FBH.

(d) The forging standard was scanned to be sure that the minimum FBH was printing. The print-out also served as a comparative standard for the forging inspection.

(e) Next, the part was centered on a turntable, rotated and scanned. The screen was monitored for noise level, relative depth of indications and gating. The gate was manually adjusted ("fast transigate circuit") during inspection for changing thickness. Radii were hand scanned in the tank.

(f) Finally, the standard print-out and forging record were compared and the size of indications were estimated. The ultrasonic unit was equipped with a sensitivity time control (STC) circuit which was set so that indications of the same size, say 1/64, would record at the same amplitude regardless of their distance from the surface.

The C-Scan ultrasonic technique verified the ability of ultrasonic inspection to detect very small flaws in titanium forgings. Indications representing defects of < 1/64 to > 3/64 (compared to respective standards) were apparent. Inspection results are summarized in Table XII.

Metal-noise, as expected, was still a factor in deciphering inspection results. Using C-Scan and a focus transducer it is possible, in some cases, to distinguish noise from real flaws. Some of the noise indications are attributable to turning grooves resulting from the forging supplier's effort to meet the roughness requirement.

The typical radiographic procedure is shown in Enclosure 18. The radiographs were of excellent quality. X-ray disclosed only a single low density inclusion which was confirmed by ultrasonic inspection. The fact that x-ray did not reveal all the indications found by ultrasonic inspection is not surprising. The flaws, more than likely, are flattened-out in the best orientation for ultrasound but below x-ray sensitivity. If the flaw is thin and has its smallest dimension along the x-ray beam it will not be detected.

G

TABLE XII

TPA TITANIUM FORGINGS ULTRASONIC INSPECTION SUMMARY

	Part No.	S/N	Billet	IR No.		Condition	Disposition
	1138575	880019	RMI-T1	N/A		Half-section standard	
	1138575	880010	RMI-T1	512425		Multiple indications	*Accepted
	1138575	880018	RMI-T1	N/A		Accepted	
(a)	1138575	880005	TMCA-B	512425	(2)	indications & excess noise	*Accepted
	1138576	880008	RMI-T1	N/A		Half-section standard	
	1138576	880007	RMI-T	512424		Multiple Indications	*Accepted
	1138576	880006	RMI-T	512424		Excessive noise	*Accepted
	1138576	880005	TMCA-B	N/A		Accepted	
	1138577	880005	TMCA-B	N/A		Accepted	
	1138577	880004	TMCA-B	512422		Single Indication	Accepted - would be removed in final machining
(b)	1138577	880006	TMCA-B	N/A		Accepted	
	1138578	880013	RMI-T	N/A		Half-section standard	
	1138578	880005	RMI-T	512423		Multiple Indications	*Accepted
	1138578	880010	RMI-T	512423		Noise	Accepted
	1138578	880011	RMI-T	N/A		Accepted	
	1138578	880012	RMI-T	512423		Multiple Indications	*Accepted
	1138579-1	880001	TMCA-T2	N/A		Half-section standard	
	1138579-1	880003	TMCA-B	N/A		Accepted	
	1138579-1	880004	TMCA-B	512426		Multiple Indications	*Accepted
	1138579-1	880005	TMCA-B	512426		Multiple Indications	*Accepted
	1138579-2	880003	TMCA-B	512427		Multiple Indications	*Accepted
	1138579-2	880004	TMCA-B	N/A		Accepted	
	1138579-2	880005	TMCA-B	512427	(2)	Indications	*Accepted

*Accepted for further processing. Final acceptance was to be based upon X-ray of final machined parts.

(a) Shear standard
(b) Longitudinal standard

VII. ACCEPTANCE TESTING

All parts had been designed with excessively large OD's in order to enable both tensile and fracture toughness acceptance tests to be performed. It was the responsibility of Arcturus to fabricate and test four tensile specimens from each and every part, following vacuum annealing. An approximately 2 inch wide test ring was parted from each die forging, and a slice was removed from between the 1138579-1 and -2 pancake forgings to be used as test material representative of both parts. In addition, one 4 inch long (circumferential) piece from each die forging was shipped to an outside machining vendor for fabrication of compact tension fracture toughness specimens. These were subsequently pre-cracked and tested at room temperature in air by an independent testing laboratory.

Results of R.T. tensile tests, shown in Tables XIII and XIV covering both die-forged and pancake forged parts, indicated uniformly high strengths and excellent ductility. For the die forging tensile tests, "A" data design allowables, presented in Enclosure 19, were calculated and it is a reflection of the superior quality of the material that even the 99/95 allowables for strengths exceeded the specification minimum strength requirements.

Results of the R.T. fracture toughness tests, shown in Table XV, were considered satisfactory and in agreement with values reported by other investigators (Reference 2). A "C" data design allowable of 79.8 ksi-in$^{1/2}$ was derived and was published in the form of DRM 04.10R1, Enclosure 20.

TABLE XIII

TPA S/N 1 R.T. TENSILE PROPERTIES

ARCTURUS DIE NO.	ARCTURUS S/N	BILLET USED	DIRECTION	UTS KSI	TYS KSI	% EL (2 IN)	% R OF A	FORGING TYPE
2915	8	TMCA "B"	Tang.	119	110	16	50	Die (X-Forged)
				120	112	16	47	
				123	114	15	49	
			Radial	121	112	17	50	
	11	RMI "T"	Tang	119	110	21	60	
				119	112	17	49	
				119	112	18	45	
			Radial	119	110	18	46	
	12		Tang.	118	110	16	46	
				119	112	18	40	
				116	108	17	52	
			Radial	116	108	16	47	
2918	11	RMI "T"	Tang.	119	112	18	48	Die (X-Forged)
				120	112	20	47	
				118	110	19	49	
			Radial	119	111	16	52	
	12		Tang.	121	113	18	43	
				120	114	19	53	
				120	112	16	52	
			Radial	119	111	20	52	
	13		Tang.	122	114	18	47	
				120	112	15	51	
				121	114	16	49	
			Radial	121	113	18	47	
	14		Tang.	120	114	16	46	
				120	114	16	46	
				120	115	18	51	
			Radial	120	115	17	45	
	15		Tang.	120	114	16	50	
				120	114	16	46	
				120	114	16	51	
			Radial	120	116	15	44	

TABLE XIII(Continued)

TPA S/N 1 R.T. TENSILE PROPERTIES

ARCTURUS DIE NO.	ARCTURUS S/N	BILLET USED	DIRECTION	UTS KSI	TYS KSI	% EL (2 IN)	% R OF A	FORGING TYPE
2916	5	TMCA "B"	Tang.	120	111	12	46	Die (X-Forged)
				120	112	15	49	
				120	111	18	48	
			Radial	120	113	14	52	
	6	RMI "T"	Tang.	122	114	16	50	
				124	116	15	49	
				123	113	15	50	
			Radial	121	113	15	54	
	7		Tang.	118	109	14	52	
				115	106	14	52	
				117	108	14	52	
			Radial	114	105	13	55	
	8	RMI "T1"	Tang.	117	109	15	54	
				118	110	13	52	
				117	110	14	53	
			Radial	117	110	14	52	
2917	4	TMCA "B"	Tang.	120	111	15	47	
				120	112	14	50	
				121	112	14	50	
			Radial	122	113	14	49	
	5		Tang.	122	112	14	47	
				120	111	14	46	
				121	112	14	47	
			Radial	122	113	14	50	
	6		Tang.	122	113	15	45	
				121	113	14	50	
				124	115	13	43	
			Radial	122	114	14	46	
ANS 90297 REQUIRED:				110	100	12	25	

TABLE XIV

TPA S/N 1 R.T. TENSILE PROPERTIES

ARCTURUS DIE NO.	ARCTURUS S/N	BILLET USED	DIRECTION	UTS KSI	TYS KSI	% EL (2 IN)	% R OF A	FORGING TYPE
X292	3	TMCA "B"	Radial	119	110	12	31	Pancake (X-Forged)
				118	110	13	27	
				116	108	12	27	
			Tang.	121	114	15	33	
	4		Radial	118	110	15	31	
				118	111	12	27	
				117	109	13	27	
			Tang	118	108	13	27	
	5		Radial	118	112	15	44	
				118	110	13	33	
				118	110	15	42	
			Tang.	120	114	16	43	
X293	3		Radial	121	113	14	34	
				120	112	15	35	
				119	112	14	34	
			Tang.	121	111	12	29	
	4		Radial	119	112	13	35	
				120	114	14	33	
				120	114	14	31	
			Tang.	118	110	15	35	
	5		Radial	120	112	13	29	
				116	109	12	27	
				118	110	12	34	
			Tang.	120	113	18	37	
ANS-90297 REQUIRED:				110	100	12	25	

TABLE XV

ROOM TEMPERATURE STATIC FRACTURE TOUGHNESS TEST RESULTS OF S/N 1 TPA ROTOR DIE FORGINGS

P/N P/N	ARCTURUS S/N	PQ (Ki PS)	f (a/w)*	K_{IC}, $KSI\text{-}IN^{1/2}$
1138575	8	14.5	10.51	106.8
1138575	11	11.25	10.61	83.76
1138575	12	13.375	10.21	95.76
1138576	5	13.25	10.78	100.1
1138576	6	13.0	10.57	96.38
1138576	7	14.06	10.54	103.97
1138577	4	13.5	10.34	97.84
1138577	5	10.0	10.24	71.82**
1138577	6	12.62	10.51	93.01
1138578	11	13.0	10.54	96.09
1138578	12	13.75	10.27	98.96
1138578	13	12.94	10.54	95.66

$$* \; f\left(\frac{a}{W}\right) = 29.6 \left(\frac{a}{W}\right)^{1/2} - 185.5 \left(\frac{a}{W}\right)^{3/2} + 655.7 \left(\frac{a}{W}\right)^{5/2} - 1017 \left(\frac{a}{W}\right)^{7/2} + 638.9 \left(\frac{a}{W}\right)^{9/2}$$

Reference 4 - ASTM-E399

**Not valid per requirements of ASTM-E399.

Several 300°R tensile tests were performed to enable validity checks to be made in the interim materials test program. Four tangential tensile specimens were machined from a 4 inch long piece of test ring representative of die forging P/N 1138578, ANSC S/N 880012. Results of these tests are presented in Table XVI.

The interim materials test program results, included as Enclosure 21, were analyzed statistically and the allowable Ki for 60 cycles was then used to reassess the structural integrity of the spinner, impeller and inducer. Allowables, included in Enclosure 20, were calculated for Ki at R.T. in GH_2, at 300°R in GH_2 and at 40°R in LH_2 and, for each temperature/environment combination, 99/95 values were obtained for 1 cycle (KIC), 1000, and 10,000 cycles. As shown in Enclosure 21, the effect of the aggressive GH_2 environment was far less damaging than had been expected from previous well publicized investigations at Boeing Co., Aerojet and Rocketdyne. Flaw growth rate in GH_2, the prime governing factor in cyclic testing, was only slightly higher in GH_2 than in GH_e at R.T., and no effect was detectable at 300°R. In addition, the pancake forging (inducer) design allowable was 52 ksi-in$^{1/2}$ compared to an earlier allowable of 44.9 ksi-in$^{1/2}$ (Reference 3). A new value for die forging K_{Ic} for radial flaw growth of 35 ksi-in$^{1/2}$ was developed in LH_2,

TABLE XVI

*300°R TENSILE TEST RESULTS OF S/N 1 TPA
DIE FORGING P/N 1138578 S/N 880012

SPECIMEN S/N	UTS KSI	TYS KSI	% EL	% R OF A
888412	142	129	14	36
888412	138	125	13	38
888414	138	126	15	34
888415	143	130	14	35
AVERAGE:	140	127	14	36

*See Reference 5.

VIII. CONCLUSIONS

The data obtained from the tests described in Section VII were used to evaluate the structural adequacy of the TPA S/N 1 rotor assembly.

The turbopump components subjected to fracture mechanics analyses were the turbine discs, inducer, impellers, and spinner.

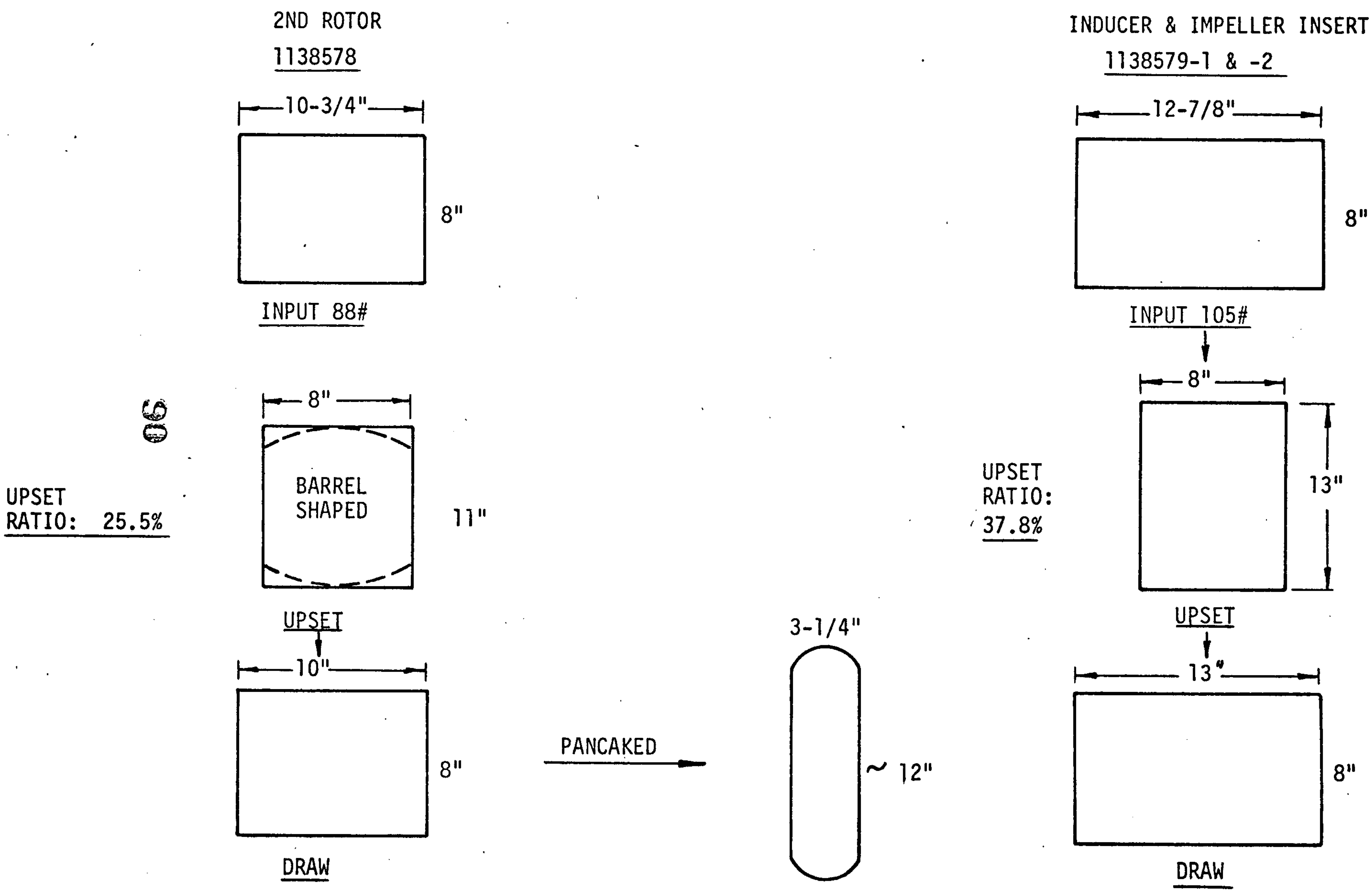
The turbine discs operate in a gaseous hydrogen environment at 300°R. The mean value of the 60 cycle K_i used in an earlier analysis was 53 KSI $\sqrt{in.}$, based upon some preliminary test data, and the .99-.95 value was established at 33 KSI $\sqrt{in.}$, using the ratio of .99-.95 K_i to mean K_i from a larger sampling of -423°F tests, as indicated. The latest test results show a mean value of 60 cycle K_i of 67 KSI $\sqrt{in.}$, which is considerably higher than that assumed in the earlier analysis. Consequently, the margins of safety obtained for the turbine discs are conservative.

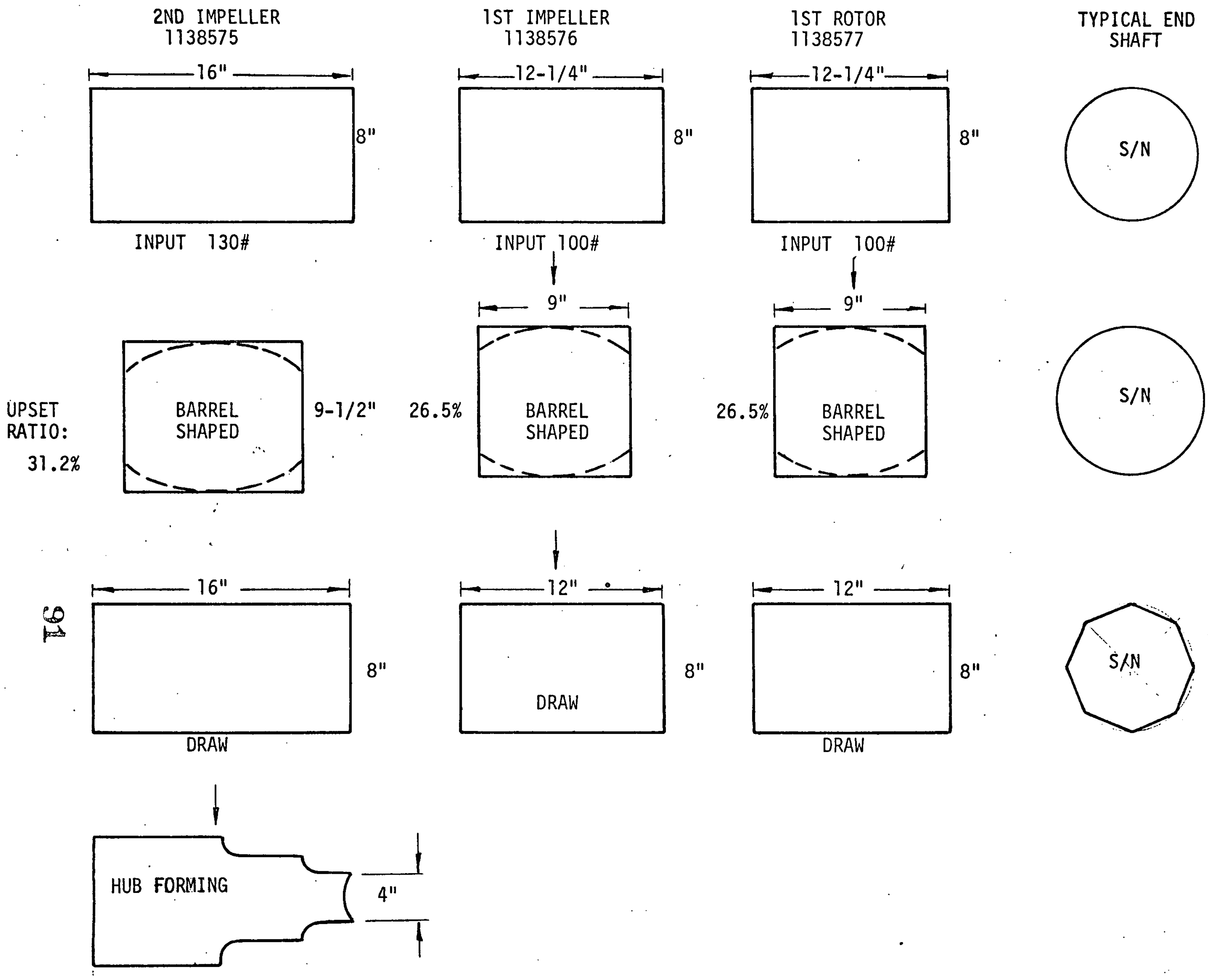
The inducer, impellers and spinner operate in a liquid hydrogen environment at approximately -423°F. The mean value of the critical stress intensity factor was assumed to be 71.6 KSI $\sqrt{in.}$, while the .99-.95 value was computed to be 44.9 KSI $\sqrt{in.}$ based upon the available experimental data for pancake forged material. The critical stress intensity after 60 cycles of operation was found using a crack propagation equation. The difference between the critical stress intensity at 60 cycles and one cycle proved to be insignificant. The latest test data for the pancake forging show an equivalent 60 cycle mean K_i of 69 KSI $\sqrt{in.}$ with a .99-.95 value of 52 KSI $\sqrt{in.}$ which is well above the value determined from available data for pancake forged material, of 44.9 KSI $\sqrt{in.}$; the test data for the die forging used for the impellers show an equivalent 60 cycle mean K_i of 54 KSI $\sqrt{in.}$ with a .99-.95 value of 35 KSI $\sqrt{in.}$ Previous experimental data for die forged material is not available. These K_i values indicate more than adequate structural integrity.

APPENDIX 1

SEQUENCE OF OPEN DIE FORGING AT

ARCTURUS MANUFACTURING CO.


2ND ROTOR
1138578
10-3/4"
8"
INPUT 88#
8"
BARREL
SHAPED
11"
UPSET
RATIO: 25.5%
UPSET
10"
8"
DRAW
PANCAKED
3-1/4"
~ 12"
INDUCER & IMPELLER INSERT
1138579-1 & -2
12-7/8"
8"
INPUT 105#
8"
13"
UPSET
RATIO:
37.8%
UPSET
13"
8"
DRAW


2ND IMPELLER
1138575
1ST IMPELLER
1138576
1ST ROTOR
1138577
TYPICAL END
SHAFT
16"
12-1/4"
12-1/4"
8"
8"
8"
S/N
INPUT 130#
INPUT 100#
INPUT 100#
9"
9"
UPSET
RATIO:
31.2%
BARREL
SHAPED
9-1/2"
26.5%
BARREL
SHAPED
26.5%
BARREL
SHAPED
S/N
16"
12"
12"
8"
8"
8"
DRAW
DRAW
DRAW
S/N
HUB FORMING
4"

APPENDIX 2

ARCTURUS' PLANNING FOR ANSC TPA FORGINGS

2010

ENGINEERING	INITIAL	DATE	COMMENTS
PRINT APPROVAL			
STOCK SIZE	8" Φ X16"	2-14-71 WH	
WEIGHT	130 lbs.	1 PC.	
TOOLING	NEW		
PRODUCTION TRYOUT			
HAMMER SIZE	25,000 &	12,000	
OTHER OPERATIONS			

(1.) CROSS WORK 1775° F

UPSET TO 11" LONG BY 9½" Φ (25,000 lb. hammer)

DRAW TO 8" Φ (25,000 lb. hammer)

DRAW ONE END (12,000 lb. hammer)

CHANGE IN EXISTING MASTER	(2.) FINISH DIE (25000 lb hammer)		

QUALITY CONTROL			
RAW MATERIAL SPEC.			
PROCESSING			

OTHER			

C2

(3) 2516

ENGINEERING	INITIAL	DATE	COMMENTS
PRINT APPROVAL			
STOCK SIZE	8" Ø x 12 1/4"	8-14-71 WH	
WEIGHT	100 lbs =	1 Pc.	
TOOLING	NEW		
PRODUCTION TRYOUT			
HAMMER SIZE	25,000		
OTHER OPERATIONS			

(1.) CROSS WORK AT 1775° F.
UPSET TO 9" HIGH
DRAW TO 7½" Ø (25,000 HAMMER)
SQUARE ENDS
CHAMFER ONE END

CHANGE IN EXISTING MASTER			

(2.) FINISH DIE (25000 lb HAMMER)

QUALITY CONTROL			
RAW MATERIAL SPEC.			
PROCESSING			

OTHER			

2511

ENGINEERING	INITIAL	DATE	COMMENTS
PRINT APPROVAL			
STOCK SIZE	8"⌀ 12 1/4"	8-14-71 W-l	
WEIGHT	100 lbs = 1%		
TOOLING	NEW		
PRODUCTION TRYOUT			
HAMMER SIZE	25,000		
OTHER OPERATIONS			

(1.) CROSS WORK AT 1775° F
UPSET TO 5" HIGH
DRAW TO 8"⌀
SQUARE ENDS
UPSET TO TOADSTOOL TO 12-14⌀

25,000 lb HAMMER

CHANGE IN EXISTING MASTER			

(2.) FINISH DIES (25,000 lb HAMMER)

QUALITY CONTROL			
RAW MATERIAL SPEC.			
PROCESSING			
OTHER			

(2) 2918

ENGINEERING	INITIAL	DATE	COMMENTS
PRINT APPROVAL			
STOCK SIZE	8" ⌀ 10 3/4"	8-14-71 WH	
WEIGHT	89 lbs = 1	pc. 10 3/4"	
TOOLING	NEW		
PRODUCTION TRYOUT			
HAMMER SIZE	25,000		
OTHER OPERATIONS			

(1.) CROSS WORK AT 1775° F

UPSET TO 8" LONG

DRAW TO 8" D — 25,000 lb hammer

UPSET TO 3 1/4" THICK

CHANGE IN EXISTING MASTER	(2.) FINISH	DIE	(25,000 lb HAMMER)
QUALITY CONTROL			
RAW MATERIAL SPEC.			
PROCESSING			
OTHER			

:2a

(5)

X-292
X-293

ENGINEERING	INITIAL	DATE	COMMENTS
PRINT APPROVAL			
STOCK SIZE	8"Ø (12 7/8")	8-14-71 WJ	
WEIGHT	105 lbs	= 1 EACH OF	X-292 Y-293
TOOLING			
PRODUCTION TRYOUT			
HAMMER SIZE	25,000		!!
OTHER OPERATIONS			
	(1.) CROSS WORK 1775°F		
	UPSET TO 8" HIGH		
	DRAW TO 8¼"Ø		
	SQUARE ENDS		
CHANGE IN EXISTING MASTER		CUT JOB INTO	(1) X-292 & (1) Y-293 PER PRINT.
QUALITY CONTROL			
RAW MATERIAL SPEC.			
PROCESSING			
OTHER			

APPENDIX 3

FORGING DETAILS OF TRY-OUT FORGINGS,

P/N 1138575
P/N 1138576
P/N 1138577
P/N 1138578

15 September 1971
PPD:mc:N8130:0148

A. <u>P/N 1138575 (die 2915) - Bottom of T4 Bar</u>:

1. Was upset from 16 to 11 inch x 9 1/2; then was necked back-out to 8 in. diameter with intermediate re-heat.

2. Hub forged on 12500 lb open hammer. Re-heated.

3. Noted small crack on hub-end and ground out.

4. Long hub drawn again after re-heat.

5. Round hub to 4 in. diameter from 4 in. square. Water cool to grind-out hub fillet cracks. Hub appears off-center.

6. Die forging planning changed to 50,000 lb hammer.

7. First die forging, followed by grinding of cracks. A large area of one side had to be ground away. Foreman indicated forging had been done too cold and metal had sheared.

8. Hit three times on 50,000 lb hammer. Cracks initiated on other side of disc. Cooled and sent to grinding.

9. Subsequent forging broke off a piece of disc and part was scrapped.

10. Second try out planned utilizing 25°F higher forging temperature (1800°F instead of 1775"F and limit number of blows to 3 from 6).

B. <u>P/N 1138576 (die 2916) - Bottom of T Bar</u>:

1. Was upset from input length to 9 inch; re-heated and then drawn back to original diameter.

2. Heavy blows of cross forged multiple while upright in die; two very small cracks noted but forge as is while near finish size. Cracks ground out prior to finish forging. Ready for finish die.

3. Hit five blows - re-heat.

4. Hit five blows - re-heat.

5. Hit twice - almost done.

6. Hit eight blows - flash formed - re-heat.

7. Hit ten blows - re-heat.

8. Hit ten blows. Completed and ready to cut.

15 September 1971

PPD:mc:N8130:0148

C. <u>P/N 1138577 (die 2917) - Bottom of T2 Bar</u>:

1. Upset from input length to 9 inch in four blows; draw out to 8 inch diameter. Small cracks in end. Ground out, dye penetrant inspect and re-heat.

2. Die forge single hub. Re-heat.

3. Hit four blows - hub off-center; re-heat.

4. Six blows - re-heat.

5. Three blows - grind fillet cracks.

6. Five blows - almost done; small hub needs more filling.

7. Ten blows - re-heat.

8. Completed and ready for cut.

15 September 1971
PPD:mc:N8130:0148

D. P/N 1138578 (die 2918) - Top of T Bar:

1. Upset from input length to 8 inch in six blows - re-heated, then drawn out to eight inch diameter. Small cracks in one end - grind out, die check and re-heat.

2. Pancake to 3 1/4 inch - some cracks in O.D. Cross forging complete. Cool.

3. Placed into finish die - 8 blows - re-heat. Inner rib not yet filled.

4. Eight blows - re-heat - small cracks noted.

5. Forged and re-heated twice - still not filled.

6. Eleven blows - completed. Sandblast and ready for cutting.

15 September 1971
PPD:mc:N8130:0148

E. P/N 1138575 S/N 3 - Bottom of T4 Bar:

1. Cross forging and hub forming completed successfully. Ready for blocking dies.

2. Five light, and one heavy blow in 25,000 lb hammer.

3. Hit 5 blows - barreling out. Re-heat.

4. Two blows - main body upsetting complete. Ready for finish dies; no cracks.

5. Five heavy blows - re-heat. No cracks.

6. Five heavy blows - re-heat. No cracks.

7. Five heavy blows - re-heat. No cracks.

8. Furnace checked at 1807°F.

9. Reversed dies so that small hub facing up.

10. Five heavy blows - small cracks around small hub fillet - hot ground and re-heat.

11. Five blows - no cracks.

12. Four blows - no cracks.

13. Six blows - no cracks.

14. Small hub was not filling, even with five more blows. Move dies to 50,000 lb hammer.

15. Part placed in larger furnace nearer 50,000 lb hammer. Temperature checked at 1801°F.

16. Four blows on 50,000 lb hammer - still hub not filled.

17. Seven blows - not filled.

18. Forging was stopped in order to vent 2915 dies. Small hub was squared off so that it can come up evenly.

19. Two heat-ups and forging cycles completed part. Cool.

APPENDIX 4

ARCTURUS FORGING PRACTICE

P/N 1138575

P/N 1138576

P/N 1138577

P/N 1138578

P/N 1138579

ARCTURUS MANUFACTURING CORPORATION
6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2915-MP-1000

IMPELLER - SECOND STAGE

ANSC P/N 1138575-1"D"
ARCTURUS DIE 2915

AUGUST 10, 1971

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2915-MP-1000

IMPELLER - SECOND STAGE

ANSC P/N 1138575-1"D"
ARCTURUS DIE 2915

AUGUST 10, 1971

PREPARED C. J. Oumi APPROVED E B Blake
DATE 8/12/71 DATE 8/13/71

B

MFG. CORP. OXNARD, CALIF.	REVISIONS	2915-MP-1000
	IMPELLER - SECOND STAGE ANSC P/N 1138575-1"D" ANSC 90297-3"A"	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

Arcturus MFG. CORP. OXNARD, CALIF.	TABLE OF CONTENTS	ANSC-TC-1000 ISSUED 8/10/71 REVISION N/C PAGE 1 of 1

ITEM #	SPEC/FORM #	DESCRIPTION	NO. OF PAGES
1	ANSC-MS-1000	Material Specification	6
2	ANSC-FC-1000	Forging Furnace Control Procedure	1
3	ANSC-FH-1000	Forging Heating Procedure	1
4	ANSC-FP-1000	Forging Practice	2
5	ANSC-HT-1000	Heat Treat Procedure	1
6	ANSC-TP-1000	Metallurgical Testing & Documentation Procedure	1
7	ANSC-UIP-1000	Ultrasonic Inspection Procedure	3
8	ANSC-SP-1000	Scan Plan	1
9	ANSC-XR-1000	Radiographic Inspection	
10	ANSC-DI-1000	Dimensional Inspection	
11	ANSC-FPPI-1000	Penetrant Inspection Procedure	1
12	ARC-5-1005	Preliminary Sales Order	
13	ARC-210	Master Card Traveler	
14	ARC-MS-1001	Heat Bar Card Record	
15	ARC-F-1001	Furnace Loading Log	
16	ARC-19298	Test Certificate Form	
17	ARC-210	Dimensional Inspection Form	
18		National Testing Laboratories Form	

ARCTURUS MFG. CORP. OXNARD, CALIF	ARCTURUS FURNACE LOADING LOG	F-1001
		ISSUED 3-4-67
		REVISION
		PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

ARCTURUS MANUFACTURING CORPORATION
6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ____________ PART NO. ____________ P. O. ____________

MATERIAL ____________ SPEC. ____________ STOCK SIZE ____________ SUPPLIER ____________

CHEMICAL ANALYSIS

HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo						

GRAIN SIZE ____________ HARDENABILITY ____________

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

S/N OR LOT NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ____________

THIS CERTIFICATION COVERS ____________ PIECES ON OUR SHIPPER ____________ DATED ____________

INCLUDING ____________

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

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SIGNED ____________

TITLE ____________

INSPECTION REPORT

DIE NO.

1ST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

LAST PC. INSPECTION

Ch. .ACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

FINAL INSPECTION

CHARACTERISTICS	ACTUAL DIM.'S	% CHECK	METHOD OF INSPECTION	TEMPLATE INSP. DATE	ACCEPT	REJECT	DATE	REMARKS

HARDNESS VERIFICATION	IDENTIFICATION
	111

ARC-210A

NATIONAL TESTING LABORATORIES

13220½ South Western Avenue

Gardena, California 90247

323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUST ER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

	YIELD				ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONG. IN 4D	ELONG. %	RED OF AREA DIM.	RED OF AREA AREA. %
XIMUMS										
NIMUMS										

IELD at .2% offset

In our opinion, the material

the requirements of the Specification.

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2916-MP-1000

IMPELLER - FIRST STAGE

ANSC P/N 1138576-1 "E"
ARCTURUS DIE 2916

AUGUST 10, 1971

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MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2916-MP-1000

IMPELLER - FIRST STAGE

ANSC P/N 1138576-1"E"
ARCTURUS DIE 2916

AUGUST 10,1971

PREPARED C. J. [illegible] APPROVED E B [illegible]

DATE 8/12/71 DATE 8/13/71

MFG. CORP. OXNARD, CALIF.	REVISIONS	2916-MP-1000
	IMPELLER - FIRST STAGE ANSC P/N 1138576-1 "E" ANSC 90297-3"A"	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following parts:

ANSC P/N	Arcturus Die #
1138579-1 "C"	X-292
1138579-2 "C"	X-293
1138575-1 "D"	2915
1138576-1 "E"	2916
1138577-1 "D"	2917
1138578-1 "E"	2918

2.0 REFERENCE DOCUMENTS: ANS-90295A, AMS 2249, ANS 90296, ANS 9032, MIL-I-6866, MIL-I-8950, FED-STD-184, MIL-STD-129.

3.0 MELTING PRACTICE: Material shall be produced by multiple melting useing the consumable electrode practice with both melting cycles performed under vacuum conditions.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent Min.	Percent Max.
Aluminum	4.70	5.60
Tin	2.00	3.00
Iron		0.25
Oxygen		0.12
Manganese		0.03
Carbon		0.05
Nitrogen		0.04
Hydrogen		0.0125
Other elements, each 1/		0.05
Other elements, total 1/		0.20
Titanium		Remainder

1/ Need Not Be Reported

SECTION 1: REQUIREMENTS

5.0 MATERIAL: The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

6.0 PRIMARY MELTING CYCLE:

6.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

6.2 Water Leakage: There shall be no water leakage during the melting operation.

6.3 Power Control: There shall be no power interruption other than momentary interruptions due to transient arch characteristics during melting.

7.0 SECONDARY MELTING CYCLE:

7.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

7.2 Water Leakage: There shall be no water leakage during or after the melting period.

7.3 Power Control: There shall be no interruption of power during the melting cycle, except the gradual power reduction required to control the size and shape of shrinkage cavity.

8.0 WELDING:

8.1 Welding Process: All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

8.2 Preparation of Electrodes: Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

9.0 CLEANING AND COATING: The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass shot) shall not be used for cleaning the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

10.0 PROPERTIES: The ingot, assembled and melted as specified in 3.0 shall be worked, pressed, forged or swaged, as required, to obtain minimum billet grain size.

10.1 Macrograin Size: Macrograin size for bars and billets shall be 0.25 inch maximum. Variation of macrograin sizes shall not be banded or grouped with predominant grain size variation limited to 0.125 inch.

11.0 DIMENSIONS AND TOLERANCES: Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

12.0 SURFACE QUALITY: The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subject to particle impact cleaning.

13.0 INTERNAL QUALITY: The material shall be uniform in quality and condition,

and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No. 3) flat-bottomed hole single point indication on the full metal thickness.

14.0 IDENTIFICATION: The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

SECTION 2: QUALITY ASSURANCE PROVISIONS

15.0 SUPPLIER RESPONSIBILITY:

15.1 Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC).

15.2 Procedures and Instructions: The supplier shall provide processing procedures or instructions to insure compliance with these requirements, copies of which shall be submitted to ANSC for review and approval prior to processing. These procedures or instructions shall be in sufficient detail so as to enable future reporducibility of material to the same processes. Copies of these procedures or instructions and records of conformance shall be retained for a period of seven years and identifiable to the specific ANSC purchase order.

15.3 Reports: Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. The reports shall include at least the following information:

(a) Raw material certifications for alloying materials (aluminum and tin).

(b) Certification to specification ANS-90296.

(c) Macrostructure photographs and macrograin size determinations, each bar and billet.

(d) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity

not in excess of normal mill practice).

(e) Chemistry, representing billets identified relative to ingot location.

(f) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(g) All information required in 14.0

(h) Processing procedures.

16.0 LOT: A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

17.0 VERIFICATION:

17.1 Material: The processing procedures supplied as specified in 15.2 shall be reviewed to assure compliance with material requirements of 5.0.

17.2 Chemical Composition: A chemical analysis shall be made from bars or billets in accordance with AMS-2249 and shall conform to requirements of 4.0

17.3 Heats: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

17.4 Welding: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

17.5 Cleaning: The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 9.0.

17.6 Properties: The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 10.0.

17.7 Dimensions and Tolerances: Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

17.8 Penetrant Inspection: Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method C using penetrant containing sulfur and chlorine not exceeding 50 parts per million (PPM).

17.9 Microstructure and Workmanship:

17.9.1 Macroetch Sample Preparation and Inspection: The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 1 requirements.

17.10 Ultrasonic Inspection: Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of the lathe turned billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of the bars while the bar is simultaneously turning and the carriage carrying the inspection head is traveling along the axial length of the bar. Inspection shall be performed in accordance with MIL-I-8950, except that, when the instrument is set so that the first back-reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, the material shall be inspected for loss of back reflection. Any loss in back reflection in excess of 50 percent of full saturation of the screen shall be considered not acceptable.

17.10.1 Noise Level: The noise level for each bar and billet shall be recorded and reported.

17.10.2 Calibration Standard: The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a depth of 0.250 inches.

17.10.3 Procedures: The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

17.10.4 Rework: Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

17.11 Identification: Bars and billets shall be visually inspected to verify conformance to Section 1 requirements.

SECTION 3 PREPARATION FOR DELIVERY

18.0 PACKAGING: Each product shall be packaged to prevent damage during handling and shipping.

18.2 Marking: Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number

SECTION 4 NOTES

19.0 INTENDED USE: Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90°F to -423°F.

19.1 Ordering Data: Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
  (1) Source surveillance
  (2) Source acceptance
  (3) Source inspection - Government.

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the parts for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus Furnace #25, a gas fired furnace with two zone control, shall be utilized in heating the subject parts for forging. Burners are L&N Speed-O-Max controllers-recorders, with series 60 controllers. N.A. flat flame-excess air types.

3.1 Temperature control on Furnace #25 is maintained by 2 Ray-O-Tube thermo-piles, located at the front and rear of the furnace.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800°F., and temperature uniformity throughout the furnace shall not exceed ± 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

1.0 ACKNOWLEDGEMENT & SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #25, as described in Arcturus procedure ANSC-FC-1000, shall have controls set at 1775 deg. F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature through-out shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure.

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

6.0 LOADING OF CROSS WORKED MULTIPLES: Cross worked multiples shall be loaded in accordance with the following procedure.

6.1 Crossworked multiples shall be loaded in serial number sequence.

6.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

7.0 LOADING OF PARTIALLY FINISHED FORGINGS: Partially finished forgings shall be loaded in accordance with the following procedure:

7.1 Partially finished forgings shall be loaded in serial number sequence.

7.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

8.0 RECORD OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

9.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 25,000# Erie steam hammer for all forging operations. Cross forging shall be performed utilizing a set of flat dies. Prefinishing and finishing operations shall be performed utilizing dies per Arcturus die drawings.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Cross Working: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000 shall be manually transferred, utilizing hand tongs, from furnace #25 and placed on flat dies installed in the 25,000# hammer. Cross working shall then be performed.

5.2 Prefinishing: Cross worked pieces, reheated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in dies conforming to Arcturus die drawings. The pieces shall be located in the die and the first hammer blow shall be made, without any lubricant, to set the piece in position. Subsequent blows shall be made utilizing a graphite impregnated oil lubricant flowed on the dies. The hammerman shall control the intensity of the blows by observing the flow of metal in the die, so that more heat is not generated in the piece than is dissipated between blows. Adiabatic heating will result in an unsatisfactory micro-structure. Forging shall cease when it is observed that the last blow has produced no flow of metal. The hazard of inducing surface or interior cracks emanates at this point.

5.3 Finishing: Prefinished forgings heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in finish dies conforming to Arcturus die drawings. The same precautions and procedures outlined under prefinishing above, shall be observed. Cooling after the final hammer operation shall be performed by quenching in water.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. Procedure if Cracking Occurs: The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-HT-1000
	Heat Treat Procedure Vacuum Annealing Procedure ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000. This procedure shall apply to the following parts.

ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1 E	2918

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, ANSC 90297 A.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Vacuum annealing equipment and controls shall be as follows:

4.1 IPSEN electrically heated furnace with 48" x 60" retort chamber.

4.2 Honeywell Control Pyrometer #A0275789015.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25^{o}F of the 1400^{o}F temperature used as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in a retort of adequate size for the load. A vacuum of 0.1 micron or less is pulled on the retort and the retort is heated to 1400^{o}F $\pm$ 25^{o}F. Time at temperature shall be one (1) hour minimum. Furnace shall then be cooled to 300^{o}F. maximum and final cooling to room temperature shall be in air. Temperature profile verification on actual parts shall be by recorded chart by thermocouple in contact with one part in the load.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS HEAT TREAT AND VERIFICATION RECORD
H. T. VENDOR ________ DATE ________ A C P. O. ________ [illegible] DR.# ________
MATERIAL ________ ARC DIE# ________ [illegible] ________
CHART SPEED [illegible] /HR. ________ TIME IN FURNACE ________
TIME OUT OF FURNACE ________ TYPE OF COOLING ________
OPERATOR [illegible] ________ S/N OF PCS. ________
ALL ITEMS [illegible] BE FILLED IN [illegible] INK ONLY. RETURN CHART WITH FORGINGS.

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE Metallurgical Testing and Documentation for ANSC 5AL-2.5 Sn ELI Forgings, ANSC 90297 A	ANSC-TP-1000 ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, ANSC 90297 A, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000, in accordance with the following procedure.

3.1 Mechanical Property Requirements: Four test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 ± 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
110,000	100,000	12	25

3.2 Microstructure: Examination for microstructure shall be in accordance with paragraph 3.7.2 of ANSC 90297A. The microstructure shall indicate that the forgings have been finished forged at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transus has been applied. The microstructure shall be uniform and indicate a wrought structure.

3.3 Macrostructure: Examination for macrostructure shall be in accordance with paragraph 3.7.3 of ANSC 90297 A. The macrostructure shall show no evidence of gross alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of ANSC 90297 A. These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{o}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 PRODUCT EVALUATION SHALL BE AS FOLLOWS:

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 ACCEPTANCE STANDARDS:

6.1 Class: The following class shall apply.

6.1.1 Class AAA:

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 Rejection Criteria:

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in ~~6.6.2.~~ 6.2.2

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 Material Disposition Control:

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol ⌧ having a 1/2 inch diameter center or a —|— having 1/2 inch maximum dimensions. The

center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

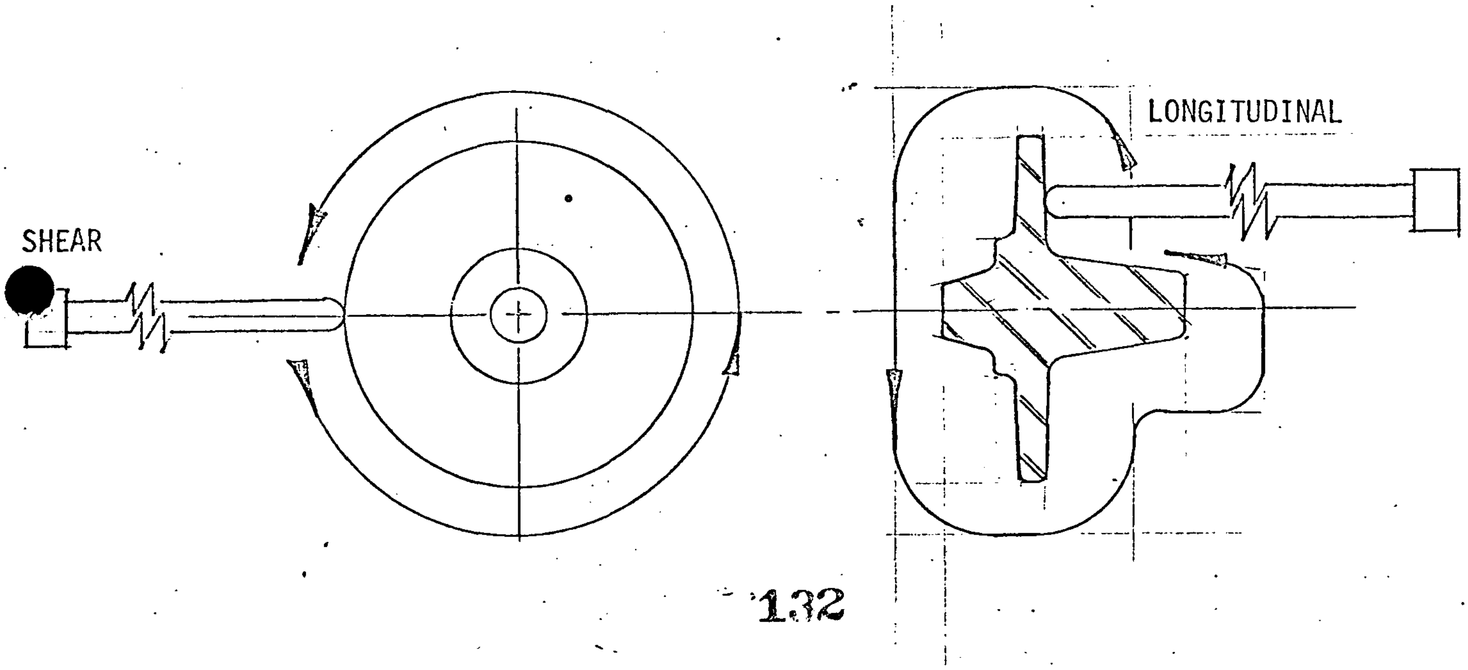
8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	2915-SP-1000
	Scan Plan for ANSC P/N 1138575-1D Arcturus 2915	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual



Arcturus MFG. CORP. OXNARD, CALIF.	~~ARCTURUS~~ PROCESS ~~PROCEDURE~~ Penetrant Inspection Procedure for ANSC 5AL-2.5 SN ELI Forgings ANSC 90297 A	ANSC-FPPI-1000 ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: MIL-I-6866B, AMend #1, Amend #2, ANSC 90297A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS: Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ______________________ W. O. NO. ______________________

CONTACT ______________________ DATE ______________________

P. O. NO. ______________________ ACK. ______________________

QTY. ______________________ CODE ______________________

PART NO. ____________ REV. ________

PRICE

DELIVERY REQUIRED ______________________ UNIT ______________________

______________________ SET UP ______________________

DELIVERY QUOTED ______________________ TOOLS ______________________

______________________ SPECIAL ______________________

PROCESSING	SPECIFICATION	NOTES
MATERIAL		
HEAT TREAT		
ULTRASONIC		
X-RAY		
ZYGLO		
MAGNAFLUX		
CLEAN		
ROUGH MACHINE		
FIN MACHINE		
TESTING		
TEST BARS		

GOV. ________ COMM. ________ CONTRACT ______________________

SPECIAL INSTRUCTIONS ______________________

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WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

	QTY.	PRICE - UNIT	AMOUNT
MAT. SPEC.			
PRIORITY			
GOV'T. CONTRACT			
HEAT TREAT			
NORMALIZE			
ANNEAL			
BRINELL — CERT ☐			
NORM & TEMP.			
GRIND.			
ZYGLO			
SAND BLAST			
MAG. INSP. — CERT ☐			
NAVY INSP. ☐			
		TOTAL	

OPERATION		EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

FOOTAGE

DMS WT.

ROUGH STOCK SIZE

DATE STOCK ORDERED:

DATE STOCK DUE IN:

IN STOCK

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

ARC 210

ARCTURUS MFG. CORP.

DATE ____________________

Arcturus MANUFACTURING CORPORATION

No. 5683A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ______________________________ PURCHASE ORDER ____________________

MATERIAL ____________________ HEAT NO. ____________________ BAR SIZE ____________________

DATE RECEIVED ____________________ TOTAL BARS REC'D __________ PAGE NO. __________ OF __________

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

CONSUMPTION

Job	$
Qty.	Lbs.

RECEIVED BY

ALLOCATION

Cut #	Length Weight	JOB NO.	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			

WITHDRAWALS

Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following parts:

ANSC P/N	Arcturus Die #
1138579-1 "C"	X-292
1138579-2 "C"	X-293
1138575-1 "D"	2915
1138576-1 "E"	2916
1138577-1 "D"	2917
1138578-1 "E"	2918

2.0 REFERENCE DOCUMENTS: ANS-90295A, AMS 2249, ANS 90296, ANS 9032, MIL-I-6866, MIL-I-8950, FED-STD-184, MIL-STD-129.

3.0 MELTING PRACTICE: Material shall be produced by multiple melting useing the consumable electrode practice with both melting cycles performed under vacuum conditions.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent Min.	Percent Max.
Aluminum	4.70	5.60
Tin	2.00	3.00
Iron		0.25
Oxygen		0.12
Manganese		0.03
Carbon		0.05
Nitrogen		0.04
Hydrogen		0.0125
Other elements, each 1/		0.05
Other elements, total 1/		0.20
Titanium		Remainder

1/ Need Not Be Reported

SECTION 1: REQUIREMENTS

5.0 MATERIAL: The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

6.0 PRIMARY MELTING CYCLE:

6.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

6.2 Water Leakage: There shall be no water leakage during the melting operation.

6.3 Power Control: There shall be no power interruption other than momentary interruptions due to transient arch characteristics during melting.

7.0 SECONDARY MELTING CYCLE:

7.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

7.2 Water Leakage: There shall be no water leakage during or after the melting period.

7.3 Power Control: There shall be no interruption of power during the melting cycle, except the gradual power reduction required to control the size and shape of shrinkage cavity.

8.0 WELDING:

8.1 Welding Process: All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

8.2 Preparation of Electrodes: Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

9.0 CLEANING AND COATING: The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass shot) shall not be used for cleaning the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

10.0 PROPERTIES: The ingot, assembled and melted as specified in 3.0 shall be worked, pressed, forged or swaged, as required, to obtain minimum billet grain size.

10.1 Macrograin Size: Macrograin size for bars and billets shall be 0.25 inch maximum. Variation of macrograin sizes shall not be banded or grouped with predominant grain size variation limited to 0.125 inch.

11.0 DIMENSIONS AND TOLERANCES: Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

12.0 SURFACE QUALITY: The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subject to particle impact cleaning.

13.0 INTERNAL QUALITY: The material shall be uniform in quality and condition,

and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No.3) flat-bottomed hole single point indication on the full metal thickness.

14.0 IDENTIFICATION: The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

SECTION 2: QUALITY ASSURANCE PROVISIONS

15.0 SUPPLIER RESPONSIBILITY:

15.1 Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC).

15.2 Procedures and Instructions: The supplier shall provide processing procedures or instructions to insure compliance with these requirements, copies of which shall be submitted to ANSC for review and approval prior to processing. These procedures or instructions shall be in sufficient detail so as to enable future reporducibility of material to the same processes. Copies of these procedures or instructions and records of conformance shall be retained for a period of seven years and identifiable to the specific ANSC purchase order.

15.3 Reports: Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. The reports shall include at least the following information:

(a) Raw material certifications for alloying materials (aluminum and tin).

(b) Certification to specification ANS-90296.

(c) Macrostructure photographs and macrograin size determinations, each bar and billet.

(d) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity

not in excess of normal mill practice).

(e) Chemistry, representing billets identified relative to ingot location.

(f) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(g) All information required in 14.0

(h) Processing procedures.

16.0 LOT: A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

17.0 VERIFICATION:

17.1 Material: The processing procedures supplied as specified in 15.2 shall be reviewed to assure compliance with material requirements of 5.0.

17.2 Chemical Composition: A chemical analysis shall be made from bars or billets in accordance with AMS-2249 and shall conform to requirements of 4.0

17.3 Heats: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

17.4 Welding: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

17.5 Cleaning: The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 9.0.

17.6 Properties: The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 10.0.

17.7 Dimensions and Tolerances: Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

17.8 Penetrant Inspection: Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method C using penetrant containing sulfur and chlorine not exceeding 50 parts per million (PPM).

17.9 Microstructure and Workmanship:

17.9.1 Macroetch Sample Preparation and Inspection: The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 1 requirements.

17.10 Ultrasonic Inspection: Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of the lathe turned billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of the bars while the bar is simultaneously turning and the carriage carrying the inspection head is traveling along the axial length of the bar. Inspection shall be performed in accordance with MIL-I-8950, except that, when the instrument is set so that the first back-reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, the material shall be inspected for loss of back reflection. Any loss in back reflection in excess of 50 percent of full saturation of the screen shall be considered not acceptable.

17.10.1 Noise Level: The noise level for each bar and billet shall be recorded and reported.

17.10.2 Calibration Standard: The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a depth of 0.250 inches.

17.10.3 Procedures: The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

17.10.4 Rework: Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

17.11 Identification: Bars and billets shall be visually inspected to verify conformance to Section 1 requirements.

SECTION 3 PREPARATION FOR DELIVERY

18.0 PACKAGING: Each product shall be packaged to prevent damage during handling and shipping.

18.2 Marking: Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number

SECTION 4 NOTES

19.0 INTENDED USE: Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90^{O}F to -423^{O}F.

19.1 Ordering Data: Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
  (1) Source surveillance
  (2) Source acceptance
  (3) Source inspection - Government.

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the parts for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus Furnace #25, a gas fired furnace with two zone control, shall be utilized in heating the subject parts for forging. Burners are L&N Speed-O-Max controllers-recorders, with series 60 controllers. N.A. flat flame-excess air types.

3.1 Temperature control on Furnace #25 is maintained by 2 Ray-O-Tube thermo-piles, located at the front and rear of the furnace.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800°F., and temperature uniformity throughout the furnace shall not exceed $\pm$ 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

1.0 ACKNOWLEDGEMENT & SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #25, as described in Arcturus procedure ANSC-FC-1000, shall have controls set at 1775 deg. F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature through-out shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure.

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

6.0 LOADING OF CROSS WORKED MULTIPLES: Cross worked multiples shall be loaded in accordance with the following procedure.

6.1 Crossworked multiples shall be loaded in serial number sequence.

6.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

7.0 LOADING OF PARTIALLY FINISHED FORGINGS: Partially finished forgings shall be loaded in accordance with the following procedure:

7.1 Partially finished forgings shall be loaded in serial number sequence.

7.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

8.0 RECORD OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

9.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 25,000# Erie steam hammer for all forging operations. Cross forging shall be performed utilizing a set of flat dies. Prefinishing and finishing operations shall be performed utilizing dies per Arcturus die drawings.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Cross Working: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000 shall be manually transferred, utilizing hand tongs, from furnace #25 and placed on flat dies installed in the 25,000# hammer. Cross working shall then be performed.

5.2 Prefinishing: Cross worked pieces, reheated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in dies conforming to Arcturus die drawings. The pieces shall be located in the die and the first hammer blow shall be made, without any lubricant, to set the piece in position. Subsequent blows shall be made utilizing a graphite impregnated oil lubricant flowed on the dies. The hammerman shall control the intensity of the blows by observing the flow of metal in the die, so that more heat is not generated in the piece than is dissipated between blows. Adiabatic heating will result in an unsatisfactory micro-structure. Forging shall cease when it is observed that the last blow has produced no flow of metal. The hazard of inducing surface or interior cracks emanates at this point.

5.3 Finishing: Prefinished forgings heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in finish dies conforming to Arcturus die drawings. The same precautions and procedures outlined under prefinishing above, shall be observed. Cooling after the final hammer operation shall be performed by quenching in water.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. Procedure if Cracking Occurs: The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000. This procedure shall apply to the following parts.

ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1 E	2918

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, ANSC 90297 A.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Vacuum annealing equipment and controls shall be as follows:

4.1 IPSEN electrically heated furnace with 48" x 60" retort chamber.

4.2 Honeywell Control Pyrometer #A0275789015.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25°F of the 1400°F temperature used as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in a retort of adequate size for the load. A vacuum of 0.1 micron or less is pulled on the retort and the retort is heated to 1400°F $\pm$ 25°F. Time at temperature shall be one (1) hour minimum. Furnace shall then be cooled to 300°F. maximum and final cooling to room temperature shall be in air. Temperature profile verification on actual parts shall be by recorded chart by thermocouple in contact with one part in the load.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS HEAT TREAT AND VERIFICATION RECORD.

H. T. VENDOR ________ DATE ________ A.C.P.O. ________ [illegible] DRG ________

MATERIAL ________ ARC DIE # ________ FURNACE # ________

CHART SPEED, /HR. ________ TIME IN FURNACE ________

TIME OUT OF FURNACE ________ T[illegible]P. OF [illegible] ________

OPERATOR ________ S/N OF [illegible] ________

ALL ITEMS [illegible] BE FILLED IN USE INK ONLY. RETURN CHART WITH FORGINGS.

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

E

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, ANSC 90297 A, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000, in accordance with the following procedure.

3.1 Mechanical Property Requirements: Four test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 $\pm$ 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
110,000	100,000	12	25

3.2 Microstructure: Examination for microstructure shall be in accordance with paragraph 3.7.2 of ANSC 90297A. The microstructure shall indicate that the forgings have been finished forged at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transus has been applied. The microstructure shall be uniform and indicate a wrought structure.

3.3 Macrostructure: Examination for macrostructure shall be in accordance with paragraph 3.7.3 of ANSC 90297 A. The macrostructure shall show no evidence of gross alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of ANSC 90297 A. These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{o}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 <u>PRODUCT EVALUATION SHALL BE AS FOLLOWS:</u>

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 <u>ACCEPTANCE STANDARDS:</u>

6.1 <u>Class:</u> The following class shall apply.

6.1.1 <u>Class AAA:</u>

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 <u>Rejection Criteria:</u>

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in 6.6.2.

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 <u>Material Disposition Control:</u>

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol having a 1/2 inch diameter center or a having 1/2 inch maximum dimensions. The

center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

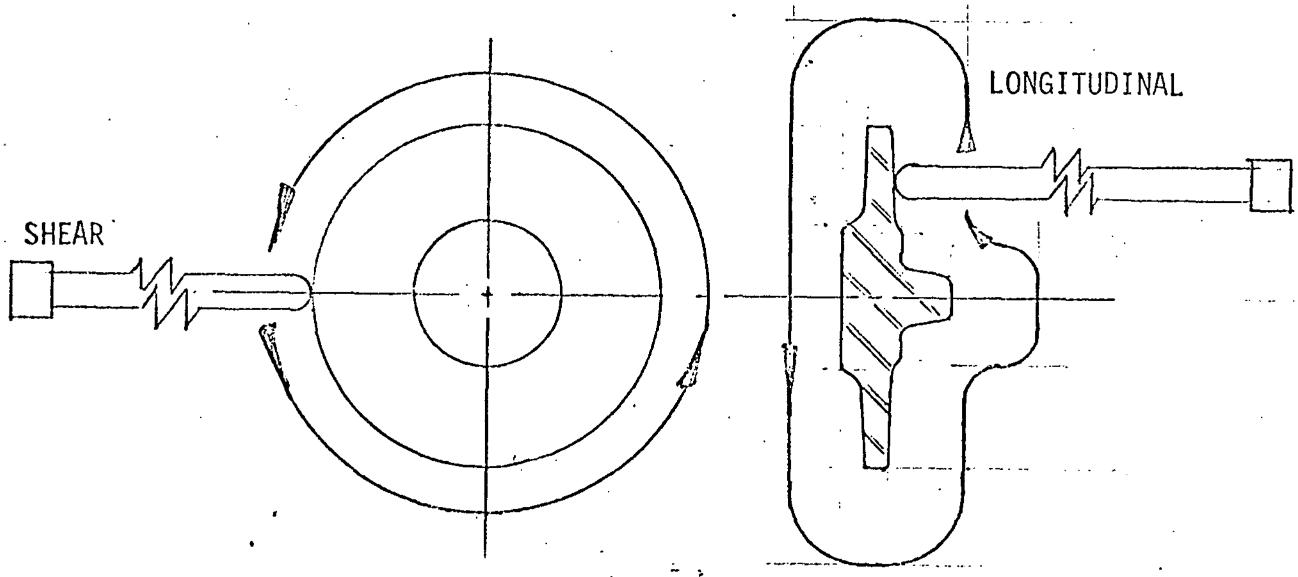
8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	2916-SP-1000
	Scan Plan for ANSC P/N 1138576-1"E" Arcturus 2916	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual



1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: MIL-I-6866B, AMend #1, Amend #2, ANSC 90297A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS: Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ______ W. O. NO. ______

CONTACT ______ DATE ______

P. O. NO. ______ ACK. ______

QTY. ______ CODE ______

PART NO. ______ REV. ______

PRICE

DELIVERY REQUIRED ______ UNIT ______

SET UP ______

DELIVERY QUOTED ______ TOOLS ______

SPECIAL ______

PROCESSING	SPECIFICATION	NOTES
MATERIAL		
HEAT TREAT		
ULTRASONIC		
X-RAY		
ZYGLO		
MAGNAFLUX		
CLEAN		
ROUGH MACHINE		
FIN MACHINE		
TESTING		
TEST BARS		

GOV. ______ COMM. ______ CONTRACT ______

SPECIAL INSTRUCTIONS ______

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

	OPERATION	EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
		QTY.	PRICE - UNIT	AMOUNT
HEAT TREAT				
NORMALIZE				
ANNEAL				
BRINELL	CERT ☐			
NORM & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP.	☐			
			TOTAL	

FOOTAGE DMS WT.	ROUGH STOCK SIZE
DATE STOCK ORDERED:	
DATE STOCK DUE IN:	
IN STOCK	

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

155

DATE ____________

Arcturus MANUFACTURING CORPORATION No. 5688A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ____________ PURCHASE ORDER ____________

MATERIAL ____________ HEAT NO. ____________ BAR SIZE ____________

DATE RECEIVED ____________ TOTAL BARS REC'D ____________ PAGE NO. ______ OF ______

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

ALLOCATION				WITHDRAWALS					
Cut #	Length Weight	JOB NO.		Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				1				
2				2				
3				3				
4				4				
5				5				
6				6				
7				7				
8				8				
9				9				
10				10				
11				11				
12				12				
13				13				
14				14				
15				15				
16				16				
17				17				
18				18				
19				19				
20				20				
21				21				
22				22				
23				23				
24				24				
25				25				
26				26				
27				27				
28				28				

CONSUMPTION

Job	$
Qty.	Lbs.

____
RECEIVED BY

ARCTURUS MFG. CORP. OXNARD, CALIF	ARCTURUS FURNACE LOADING LOG	F-1001 ISSUED 3-4-67 REVISION PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ______ PART NO. ______ P. O. ______

MATERIAL ______ SPEC. ______ STOCK SIZE ______ SUPPLIER ______

CHEMICAL ANALYSIS

HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo						

GRAIN SIZE ______ HARDENABILITY ______

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

[illegible]N OR [illegible]T NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ______

THIS CERTIFICATION COVERS ______ PIECES ON OUR SHIPPER ______ DATED ______

INCLUDING ______

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

SIGNED ______

TITLE ______

158

INSPECTION REPORT

DIE NO.

1ST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

LAST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

FINAL INSPECTION

CHARACTERISTICS	ACTUAL DIM.'S	% CHECK	METHOD OF INSPECTION	TEMPLATE INSP. DATE	ACCEPT	REJECT	DATE	REMARKS

HARDNESS VERIFICATION	IDENTIFICATION
159	

ARC-210A

13220½ South Western Avenue
Gardena, California 90247
323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUST ER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

	YIELD				ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONG. IN 4D	ELONG. %	RED OF AREA DIM.	RED OF AREA AREA, %
XIMUMS										
NIMUMS										

IELD at .2% offset

160 In our opinion, the material
the requirements of the Specification.

Arcturus MANUFACTURING CORPORATION
6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2917-MP-1000

ROTOR, TURBINE - FIRST STAGE

ANSC P/N 1138577-1 "D"
ARCTURUS DIE 2917

AUGUST 10, 1971

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2917-MP-1000

ROTOR, TURBINE - FIRST STAGE

ANSC P/N 1138577-1 "D"
ARCTURUS DIE 2917

AUGUST 10, 1971

PREPARED C. J. [illegible] APPROVED E B Blake
DATE 8/12/71 DATE 8/13/71

Sundstrand MFG. CORP. OXNARD, CALIF.	REVISIONS	2917-MP-1000
	ROTOR, TURBINE - FIRST STAGE ANSC P/N 1138577-1"D" ANSC 90297-3 "A"	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following parts:

ANSC P/N	Arcturus Die #
1138579-1 "C"	X-292
1138579-2 "C"	X-293
1138575-1 "D"	2915
1138576-1 "E"	2916
1138577-1 "D"	2917
1138578-1 "E"	2918

2.0 REFERENCE DOCUMENTS: ANS-90295A, AMS 2249, ANS 90296, ANS 9032, MIL-I-6866, MIL-I-8950, FED-STD-184, MIL-STD-129.

3.0 MELTING PRACTICE: Material shall be produced by multiple melting useing the consumable electrode practice with both melting cycles performed under vacuum conditions.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent	
	Min.	Max.
Aluminum	4.70	5.60
Tin	2.00	3.00
Iron		0.25
Oxygen		0.12
Manganese		0.03
Carbon		0.05
Nitrogen		0.04
Hydrogen		0.0125
Other elements, each 1/		0.05
Other elements, total 1/		0.20
Titanium		Remainder

1/ Need Not Be Reported

SECTION 1: REQUIREMENTS

5.0 MATERIAL: The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

6.0 PRIMARY MELTING CYCLE:

6.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

6.2 Water Leakage: There shall be no water leakage during the melting operation.

6.3 Power Control: There shall be no power interruption other than momentary interruptions due to transient arch characteristics during melting.

7.0 SECONDARY MELTING CYCLE:

7.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

7.2 Water Leakage: There shall be no water leakage during or after the melting period.

7.3 Power Control: There shall be no interruption of power during the melting cycle, except the gradual power reduction required to control the size and shape of shrinkage cavity.

8.0 WELDING:

8.1 Welding Process: All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

8.2 Preparation of Electrodes: Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

9.0 CLEANING AND COATING: The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass shot) shall not be used for cleaning the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

10.0 PROPERTIES: The ingot, assembled and melted as specified in 3.0 shall be worked, pressed, forged or swaged, as required, to obtain minimum billet grain size.

10.1 Macrograin Size: Macrograin size for bars and billets shall be 0.25 inch maximum. Variation of macrograin sizes shall not be banded or grouped with predominant grain size variation limited to 0.125 inch.

11.0 DIMENSIONS AND TOLERANCES: Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

12.0 SURFACE QUALITY: The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subject to particle impact cleaning.

13.0 INTERNAL QUALITY: The material shall be uniform in quality and condition,

and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No. 3) flat-bottomed hole single point indication on the full metal thickness.

14.0 IDENTIFICATION: The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

SECTION 2: QUALITY ASSURANCE PROVISIONS

15.0 SUPPLIER RESPONSIBILITY:

15.1 Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC).

15.2 Procedures and Instructions: The supplier shall provide processing procedures or instructions to insure compliance with these requirements, copies of which shall be submitted to ANSC for review and approval prior to processing. These procedures or instructions shall be in sufficient detail so as to enable future reporducibility of material to the same processes. Copies of these procedures or instructions and records of conformance shall be retained for a period of seven years and identifiable to the specific ANSC purchase order.

15.3 Reports: Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. The reports shall include at least the following information:

(a) Raw material certifications for alloying materials (aluminum and tin).

(b) Certification to specification ANS-90296.

(c) Macrostructure photographs and macrograin size determinations, each bar and billet.

(d) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity

not in excess of normal mill practice).

(e) Chemistry, representing billets identified relative to ingot location.

(f) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(g) All information required in 14.0

(h) Processing procedures.

16.0 LOT: A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

17.0 VERIFICATION:

17.1 Material: The processing procedures supplied as specified in 15.2 shall be reviewed to assure compliance with material requirements of 5.0.

17.2 Chemical Composition: A chemical analysis shall be made from bars or billets in accordance with AMS-2249 and shall conform to requirements of 4.0

17.3 Heats: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

17.4 Welding: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

17.5 Cleaning: The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 9.0.

17.6 Properties: The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 10.0.

17.7 Dimensions and Tolerances: Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

17.8 Penetrant Inspection: Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method C using penetrant containing sulfur and chlorine not exceeding 50 parts per million (PPM).

17.9 Microstructure and Workmanship:

17.9.1 Macroetch Sample Preparation and Inspection: The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 1 requirements.

17.10 Ultrasonic Inspection: Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of the lathe turned billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of the bars while the bar is simultaneously turning and the carriage carrying the inspection head is traveling along the axial length of the bar. Inspection shall be performed in accordance with MIL-I-8950, except that, when the instrument is set so that the first back-reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, the material shall be inspected for loss of back reflection. Any loss in back reflection in excess of 50 percent of full saturation of the screen shall be considered not acceptable.

17.10.1 Noise Level: The noise level for each bar and billet shall be recorded and reported.

17.10.2 Calibration Standard: The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a depth of 0.250 inches.

17.10.3 Procedures: The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

17.10.4 Rework: Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

17.11 Identification: Bars and billets shall be visually inspected to verify conformance to Section 1 requirements.

SECTION 3 PREPARATION FOR DELIVERY

18.0 PACKAGING: Each product shall be packaged to prevent damage during handling and shipping.

18.2 Marking: Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number

SECTION 4 NOTES

19.0 INTENDED USE: Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90°F to -423°F.

19.1 Ordering Data: Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
  (1) Source surveillance
  (2) Source acceptance
  (3) Source inspection - Government.

ARCTURUS MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FC-1000
	Forging Furnace Control ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/C
		PAGE 1 of 1

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the parts for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus Furnace #25, a gas fired furnace with two zone control, shall be utilized in heating the subject parts for forging. Burners are L&N Speed-O-Max controllers-recorders, with series 60 controllers. N.A. flat flame-excess air types.

3.1 Temperature control on Furnace #25 is maintained by 2 Ray-O-Tube thermo-piles, located at the front and rear of the furnace.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800°F., and temperature uniformity throughout the furnace shall not exceed $\pm$ 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

1.0 ACKNOWLEDGEMENT & SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #25, as described in Arcturus procedure ANSC-FC-1000, shall have controls set at 1775 deg. F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature through-out shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure.

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

6.0 LOADING OF CROSS WORKED MULTIPLES: Cross worked multiples shall be loaded in accordance with the following procedure.

6.1 Crossworked multiples shall be loaded in serial number sequence.

6.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

7.0 LOADING OF PARTIALLY FINISHED FORGINGS: Partially finished forgings shall be loaded in accordance with the following procedure:

7.1 Partially finished forgings shall be loaded in serial number sequence.

7.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

8.0 RECORD OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

9.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 25,000# Erie steam hammer for all forging operations. Cross forging shall be performed utilizing a set of flat dies. Prefinishing and finishing operations shall be performed utilizing dies per Arcturus die drawings.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Cross Working: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000 shall be manually transferred, utilizing hand tongs, from furnace #25 and placed on flat dies installed in the 25,000# hammer. Cross working shall then be performed.

5.2 Prefinishing: Cross worked pieces, reheated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in dies conforming to Arcturus die drawings. The pieces shall be located in the die and the first hammer blow shall be made, without any lubricant, to set the piece in position. Subsequent blows shall be made utilizing a graphite impregnated oil lubricant flowed on the dies. The hammerman shall control the intensity of the blows by observing the flow of metal in the die, so that more heat is not generated in the piece than is dissipated between blows. Adiabatic heating will result in an unsatisfactory micro-structure. Forging shall cease when it is observed that the last blow has produced no flow of metal. The hazard of inducing surface or interior cracks emanates at this point.

5.3 Finishing: Prefinished forgings heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in finish dies conforming to Arcturus die drawings. The same precautions and procedures outlined under prefinishing above, shall be observed. Cooling after the final hammer operation shall be performed by quenching in water.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. Procedure if Cracking Occurs: The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000. This procedure shall apply to the following parts.

ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1 E	2918

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, ANSC 90297 A.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Vacuum annealing equipment and controls shall be as follows:

4.1 IPSEN electrically heated furnace with 48" x 60" retort chamber.

4.2 Honeywell Control Pyrometer #A0275789015.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25°F of the 1400°F temperature used as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in a retort of adequate size for the load. A vacuum of 0.1 micron or less is pulled on the retort and the retort is heated to 1400°F $\pm$ 25°F. Time at temperature shall be one (1) hour minimum. Furnace shall then be cooled to 300°F. maximum and final cooling to room temperature shall be in air. Temperature profile verification on actual parts shall be by recorded chart by thermocouple in contact with one part in the load.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS HEAT TREAT AND VERIFICATION RECORD

H. T. VENDOR ______ DATE ______ AC P. O. ______ [illegible] DRA ______

MATERIAL ______ ARC DIE # ______ FURNACE # ______

CHART SPEED /HR. ______ TIME IN FURNACE ______

TIME OUT OF FURNACE ______ TYPE OF COOLING ______

OPERATOR ______ S/N OF PCS. ______

ALL ITEMS MUST BE FILLED IN USE INK ONLY. RETURN CHART WITH FORGINGS.

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, ANSC 90297 A, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000, in accordance with the following procedure.

3.1 Mechanical Property Requirements: Four test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 $\pm$ 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
110,000	100,000	12	25

3.2 Microstructure: Examination for microstructure shall be in accordance with paragraph 3.7.2 of ANSC 90297A. The microstructure shall indicate that the forgings have been finished forged at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transus has been applied. The microstructure shall be uniform and indicate a wrought structure.

3.3 Macrostructure: Examination for macrostructure shall be in accordance with paragraph 3.7.3 of ANSC 90297 A. The macrostructure shall show no evidence of gross alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of ANSC 90297 A. These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{0}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 PRODUCT EVALUATION SHALL BE AS FOLLOWS:

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 ACCEPTANCE STANDARDS:

6.1 Class: The following class shall apply.

6.1.1 Class AAA:

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 Rejection Criteria:

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in 6.6.2.

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 Material Disposition Control:

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol having a 1/2 inch diameter center or a having 1/2 inch maximum dimensions. The

center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

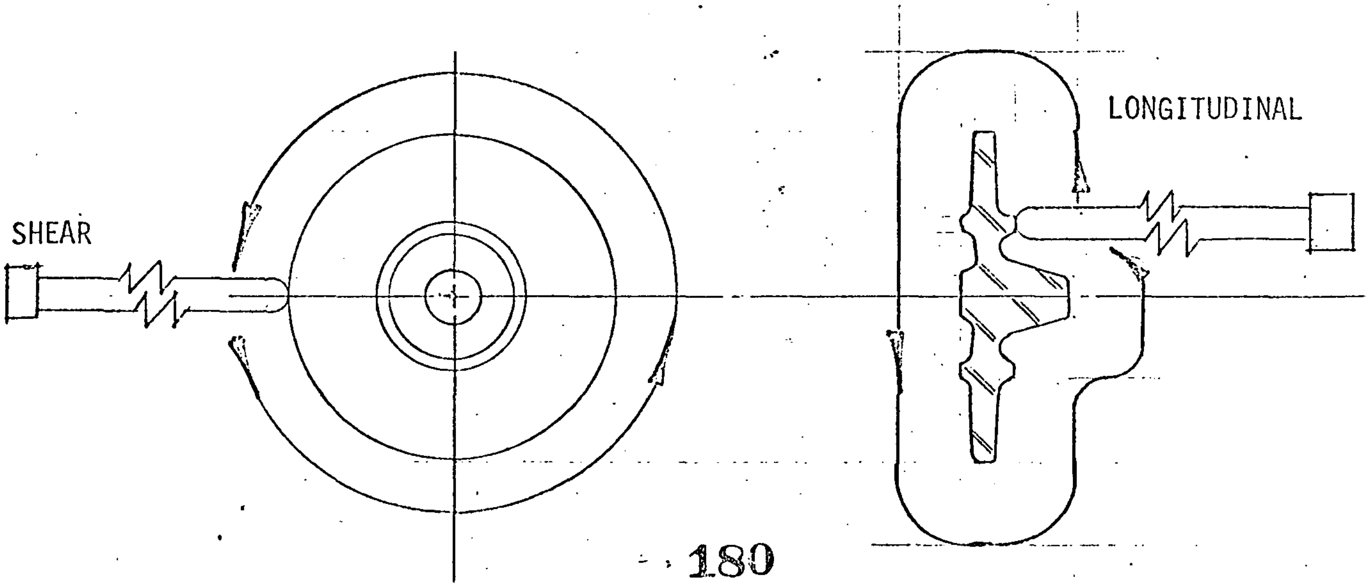
8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	2917-SP-1000
	Scan Plan for ANSC P/N 1138577-1D Arcturus 2917	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual



Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FPPI-1000
	Penetrant Inspection Procedure for ANSC 5AL-2.5 SN ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: MIL-I-6866B, AMend #1, Amend #2, ANSC 90297A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS: Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ____________________ W. O. NO. ____________________

CONTACT ____________________ DATE ____________________

P. O. NO. ____________________ ACK. ____________________

QTY. ____________________ CODE ____________________

PART NO. ____________ REV. ________

PRICE

DELIVERY REQUIRED ____________________ UNIT ____________________

SET UP ____________________

DELIVERY QUOTED ____________________ TOOLS ____________________

SPECIAL ____________________

PROCESSING	SPECIFICATION	NOTES
MATERIAL		
HEAT TREAT		
ULTRASONIC		
X-RAY		
ZYGLO		
MAGNAFLUX		
CLEAN		
ROUGH MACHINE		
FIN MACHINE		
TESTING		
TEST BARS		

GOV. ________ COMM. ________ CONTRACT ____________________

SPECIAL INSTRUCTIONS ____________________

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

OPERATION		EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
		QTY.	PRICE - UNIT	AMOUNT
HEAT TREAT				
NORMALIZE				
ANNEAL				
BRINELL	CERT ☐			
NORM & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP. ☐				
			TOTAL	

FOOTAGE DMS WT.	ROUGH STOCK SIZE
DATE STOCK ORDERED:	
DATE STOCK DUE IN:	
IN STOCK	

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

ARC 210

ARCTURUS MFG. CORP.

Arcturus MANUFACTURING CORPORATION

DATE ____________

No. 5691A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ____________ PURCHASE ORDER ____________

MATERIAL ____________ HEAT NO. ____________ BAR SIZE ____________

DATE RECEIVED ____________ TOTAL BARS REC'D ____________ PAGE NO. ________ OF ________

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

CONSUMPTION

Job	$
Qty.	Lbs.

____
RECEIVED BY

ALLOCATION

Cut #	Length Weight	JOB NO.	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			

WITHDRAWALS

Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
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28				

ARCTURUS MFG. CORP. OXNARD, CALIF	ARCTURUS FURNACE LOADING LOG	F-1001
		ISSUED 3-4-67
		REVISION
		PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ______________ PART NO. ______________ P. O. ______________

MATERIAL ______________ SPEC. ______________ STOCK SIZE ______________ SUPPLIER ______________

CHEMICAL ANALYSIS

HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo						

GRAIN SIZE ______________ HARDENABILITY ______________

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

S/N OR T NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ______________

THIS CERTIFICATION COVERS ______________ PIECES ON OUR SHIPPER ______________ DATED ______________

INCLUDING ______________

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

SIGNED ______________

TITLE ______________

186

INSPECTION REPORT

DIE NO.

1ST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

LAST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

FINAL INSPECTION

CHARACTERISTICS	ACTUAL DIM.'S	% CHECK	METHOD OF INSPECTION	TEMPLATE INSP. DATE	ACCEPT	REJECT	DATE	REMARKS

HARDNESS VERIFICATION	IDENTIFICATION
187	

ARC-210A

13220½ South Western Avenue
Gardena, California 90247
323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUST ER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

			YIELD		ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.I.	ELONG. IN 4D	%	RED OF AREA DIM.	AREA, %
XIMUMS										
NIMUMS										

IELD at .2% offset

In our opinion, the material .
the requirements of the Specification.

Arcturus MANUFACTURING CORPORATION
6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES, CONTROLS AND DOCUMENTATION FORMS FOR PROCESSING ANSC 90297-3"A" FORGINGS - ARCTURUS 2918-MP-1000

ROTOR, TURBINE - SECOND STAGE

ANSC P/N 1138578-1 "E"
ARCTURUS DIE 2918

AUGUST 10, 1971

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-3"A"
FORGINGS - ARCTURUS 2918-MP-1000

ROTOR, TURBINE - SECOND STAGE

ANSC P/N 1138578-1 "E"
ARCTURUS DIE 2918

AUGUST 10, 1971

PREPARED C. J. Ouvaiola APPROVED E B Bl...
DATE 8/12/71 DATE 8/13/71

C 3

Arcturus MFG. CORP. OXNARD, CALIF.	REVISIONS	2918-MP-1000
	ROTOR, TURBINE - SECOND STAGE ANSC P/N 1138578-1 "E" ANSC 90297-3 "A"	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following parts:

ANSC P/N	Arcturus Die #
1138579-1 "C"	X-292
1138579-2 "C"	X-293
1138575-1 "D"	2915
1138576-1 "E"	2916
1138577-1 "D"	2917
1138578-1 "E"	2918

2.0 REFERENCE DOCUMENTS: ANS-90295A, AMS 2249, ANS 90296, ANS 9032, MIL-I-6866, MIL-I-8950, FED-STD-184, MIL-STD-129.

3.0 MELTING PRACTICE: Material shall be produced by multiple melting useing the consumable electrode practice with both melting cycles performed under vacuum conditions.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent Min.	Percent Max.
Aluminum	4.70	5.60
Tin	2.00	3.00
Iron		0.25
Oxygen		0.12
Manganese		0.03
Carbon		0.05
Nitrogen		0.04
Hydrogen		0.0125
Other elements, each 1/		0.05
Other elements, total 1/		0.20
Titanium		Remainder

1/ Need Not Be Reported

SECTION 1: REQUIREMENTS

5.0 MATERIAL: The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

6.0 PRIMARY MELTING CYCLE:

6.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

6.2 Water Leakage: There shall be no water leakage during the melting operation.

6.3 Power Control: There shall be no power interruption other than momentary interruptions due to transient arch characteristics during melting.

7.0 SECONDARY MELTING CYCLE:

7.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

7.2 Water Leakage: There shall be no water leakage during or after the melting period.

7.3 Power Control: There shall be no interruption of power during the melting cycle, except the gradual power reduction required to control the size and shape of shrinkage cavity.

8.0 WELDING:

8.1 Welding Process: All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

8.2 Preparation of Electrodes: Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

9.0 CLEANING AND COATING: The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass shot) shall not be used for cleaning the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

10.0 PROPERTIES: The ingot, assembled and melted as specified in 3.0 shall be worked, pressed, forged or swaged, as required, to obtain minimum billet grain size.

10.1 Macrograin Size: Macrograin size for bars and billets shall be 0.25 inch maximum. Variation of macrograin sizes shall not be banded or grouped with predominant grain size variation limited to 0.125 inch.

11.0 DIMENSIONS AND TOLERANCES: Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

12.0 SURFACE QUALITY: The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subject to particle impact cleaning.

13.0 INTERNAL QUALITY: The material shall be uniform in quality and condition,

and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No. 3) flat-bottomed hole single point indication on the full metal thickness.

14.0 IDENTIFICATION: The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

SECTION 2: QUALITY ASSURANCE PROVISIONS

15.0 SUPPLIER RESPONSIBILITY:

15.1 Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC).

15.2 Procedures and Instructions: The supplier shall provide processing procedures or instructions to insure compliance with these requirements, copies of which shall be submitted to ANSC for review and approval prior to processing. These procedures or instructions shall be in sufficient detail so as to enable future reporducibility of material to the same processes. Copies of these procedures or instructions and records of conformance shall be retained for a period of seven years and identifiable to the specific ANSC purchase order.

15.3 Reports: Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. The reports shall include at least the following information:

(a) Raw material certifications for alloying materials (aluminum and tin).

(b) Certification to specification ANS-90296.

(c) Macrostructure photographs and macrograin size determinations, each bar and billet.

(d) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity

not in excess of normal mill practice).

(e) Chemistry, representing billets identified relative to ingot location.

(f) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(g) All information required in 14.0

(h) Processing procedures.

16.0 LOT: A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

17.0 VERIFICATION:

17.1 Material: The processing procedures supplied as specified in 15.2 shall be reviewed to assure compliance with material requirements of 5.0.

17.2 Chemical Composition: A chemical analysis shall be made from bars or billets in accordance with AMS-2249 and shall conform to requirements of 4.0

17.3 Heats: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

17.4 Welding: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

17.5 Cleaning: The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 9.0.

17.6 Properties: The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 10.0.

17.7 Dimensions and Tolerances: Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

17.8 Penetrant Inspection: Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method C using penetrant containing sulfur and chlorine not exceeding 50 parts per million (PPM).

17.9 Microstructure and Workmanship:

17.9.1 Macroetch Sample Preparation and Inspection: The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 1 requirements.

17.10 Ultrasonic Inspection: Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of the lathe turned billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of the bars while the bar is simultaneously turning and the carriage carrying the inspection head is traveling along the axial length of the bar. Inspection shall be performed in accordance with MIL-I-8950, except that, when the instrument is set so that the first back-reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, the material shall be inspected for loss of back reflection. Any loss in back reflection in excess of 50 percent of full saturation of the screen shall be considered not acceptable.

17.10.1 Noise Level: The noise level for each bar and billet shall be recorded and reported.

17.10.2 Calibration Standard: The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a depth of 0.250 inches.

17.10.3 Procedures: The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

17.10.4 Rework: Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

17.11 Identification: Bars and billets shall be visually inspected to verify conformance to Section 1 requirements.

SECTION 3 PREPARATION FOR DELIVERY

18.0 PACKAGING: Each product shall be packaged to prevent damage during handling and shipping.

18.2 Marking: Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number

SECTION 4 NOTES

19.0 INTENDED USE: Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90°F to -423°F.

19.1 Ordering Data: Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
    (1) Source surveillance
    (2) Source acceptance
    (3) Source inspection - Government.

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the parts for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus Furnace #25, a gas fired furnace with two zone control, shall be utilized in heating the subject parts for forging. Burners are L&N Speed-O-Max controllers-recorders, with series 60 controllers. N.A. flat flame-excess air types.

3.1 Temperature control on Furnace #25 is maintained by 2 Ray-O-Tube thermo-piles, located at the front and rear of the furnace.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800°F., and temperature uniformity throughout the furnace shall not exceed $\pm$ 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FH-1000
	Forging Heating Procedure ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 ACKNOWLEDGEMENT & SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #25, as described in Arcturus procedure ANSC-FC-1000, shall have controls set at 1775 deg. F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature through-out shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure.

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

6.0 LOADING OF CROSS WORKED MULTIPLES: Cross worked multiples shall be loaded in accordance with the following procedure.

6.1 Crossworked multiples shall be loaded in serial number sequence.

6.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

7.0 LOADING OF PARTIALLY FINISHED FORGINGS: Partially finished forgings shall be loaded in accordance with the following procedure:

7.1 Partially finished forgings shall be loaded in serial number sequence.

7.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

8.0 RECORD OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

9.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 25,000# Erie steam hammer for all forging operations. Cross forging shall be performed utilizing a set of flat dies. Prefinishing and finishing operations shall be performed utilizing dies per Arcturus die drawings.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Cross Working: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000 shall be manually transferred, utilizing hand tongs, from furnace #25 and placed on flat dies installed in the 25,000# hammer. Cross working shall then be performed.

5.2 Prefinishing: Cross worked pieces, reheated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in dies conforming to Arcturus die drawings. The pieces shall be located in the die and the first hammer blow shall be made, without any lubricant, to set the piece in position. Subsequent blows shall be made utilizing a graphite impregnated oil lubricant flowed on the dies. The hammerman shall control the intensity of the blows by observing the flow of metal in the die, so that more heat is not generated in the piece than is dissipated between blows. Adiabatic heating will result in an unsatisfactory micro-structure. Forging shall cease when it is observed that the last blow has produced no flow of metal. The hazard of inducing surface or interior cracks emanates at this point.

5.3 Finishing: Prefinished forgings heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in finish dies conforming to Arcturus die drawings. The same precautions and procedures outlined under prefinishing above, shall be observed. Cooling after the final hammer operation shall be performed by quenching in water.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. <u>Procedure if Cracking Occurs:</u> The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-HT-1000
	Heat Treat Procedure Vacuum Annealing Procedure ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000. This procedure shall apply to the following parts.

ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1 E	2918

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, ANSC 90297 A.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Vacuum annealing equipment and controls shall be as follows:

4.1 IPSEN electrically heated furnace with 48" x 60" retort chamber.

4.2 Honeywell Control Pyrometer #A0275789015.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25°F of the 1400°F temperature used as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in a retort of adequate size for the load. A vacuum of 0.1 micron or less is pulled on the retort and the retort is heated to 1400°F $\pm$ 25°F. Time at temperature shall be one (1) hour minimum. Furnace shall then be cooled to 300°F. maximum and final cooling to room temperature shall be in air. Temperature profile verification on actual parts shall be by recorded chart by thermocouple in contact with one part in the load.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS HEAT TREAT AND VERIFICATION RECORD

H. T. VENDOR ________ DATE ________ A C P. O. ________ [illegible] DR# ________
MATERIAL ________ [illegible] ________ FURNACE# ________
CHARGE SPACING/ [illegible] ________ TIME IN FURNACE ________
TIME OUT OF FURNACE ________ TYPE OF COOLING ________
OPERATOR [illegible] ________ S/N OF PCS. ________
ALL ITEMS [illegible] BE FILLED IN USE INK ONLY. RETURN CHART WITH FORGINGS.

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, ANSC 90297 A, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000, in accordance with the following procedure.

3.1 Mechanical Property Requirements: Four test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 $\pm$ 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
110,000	100,000	12	25

3.2 Microstructure: Examination for microstructure shall be in accordance with paragraph 3.7.2 of ANSC 90297A. The microstructure shall indicate that the forgings have been finished forged at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transus has been applied. The microstructure shall be uniform and indicate a wrought structure.

3.3 Macrostructure: Examination for macrostructure shall be in accordance with paragraph 3.7.3 of ANSC 90297 A. The macrostructure shall show no evidence of gross alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of ANSC 90297 A. These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{o}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 PRODUCT EVALUATION SHALL BE AS FOLLOWS:

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 ACCEPTANCE STANDARDS:

6.1 Class: The following class shall apply.

6.1.1 Class AAA:

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 Rejection Criteria:

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in 6.6.2.

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 Material Disposition Control:

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol having a 1/2 inch diameter center or a having 1/2 inch maximum dimensions. The

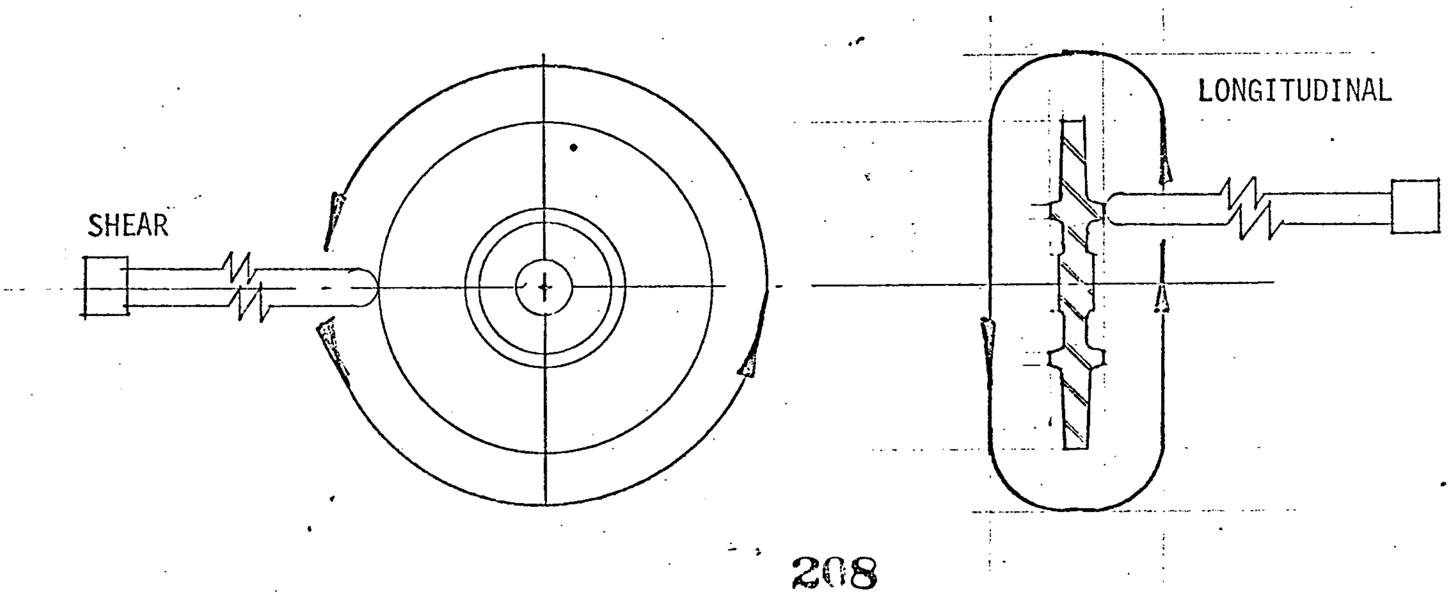
center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual.



Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FPPI-1000
	Penetrant Inspection Procedure for ANSC 5AL-2.5 SN ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: MIL-I-6866B, AMend #1, Amend #2, ANSC 90297A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS: Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ____________________ W. O. NO. ____________________

CONTACT ____________________ DATE ____________________

P. O. NO. ____________________ ACK. ____________________

QTY. ____________________ CODE ____________________

PART NO. ____________ REV. ________

PRICE

DELIVERY REQUIRED ____________________ UNIT ____________________

SET UP ____________________

DELIVERY QUOTED ____________________ TOOLS ____________________

SPECIAL ____________________

PROCESSING	SPECIFICATION	NOTES
MATERIAL		
HEAT TREAT		
ULTRASONIC		
X-RAY		
ZYGLO		
MAGNAFLUX		
CLEAN		
ROUGH MACHINE		
FIN MACHINE		
TESTING		
TEST BARS		

GOV. ________ COMM. ________ CONTRACT ____________________

SPECIAL INSTRUCTIONS ____________________

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

	OPERATION	EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

		QTY.	PRICE - UNIT	AMOUNT
MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
HEAT TREAT				
NORMALIZE				
ANNEAL				
BRINELL	CERT ☐			
NORM & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP. ☐				
			TOTAL	

FOOTAGE

DMS WT.

ROUGH STOCK SIZE

DATE STOCK ORDERED:

DATE STOCK DUE IN:

IN STOCK

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

ARC 210

ARCTURUS MFG. CORP.

Arcturus MANUFACTURING CORPORATION

DATE ____________

No. 5694A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ____________ PURCHASE ORDER ____________

MATERIAL ____________ HEAT NO. ____________ BAR SIZE ____________

DATE RECEIVED ____________ TOTAL BARS REC'D ____________ PAGE NO. ______ OF ______

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

CONSUMPTION

Job	$
Qty.	Lbs.

RECEIVED BY ____________

ALLOCATION				WITHDRAWALS					
Cut #	Length Weight	JOB NO.		Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				1				
2				2				
3				3				
4				4				
5				5				
6				6				
7				7				
8				8				
9				9				
10				10				
11				11				
12				12				
13				13				
14				14				
15				15				
16				16				
17				17				
18				18				
19				19				
20				20				
21				21				
22				22				
23				23				
24				24				
25				25				
26				26				
27				27				
28				28				

ARCTURUS MFG. CORP. OXNARD, CALIF	ARCTURUS FURNACE LOADING LOG	F-1001
		ISSUED 3-4-67
		REVISION
		PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ______ PART NO. ______ P. O. ______

MATERIAL ______ SPEC. ______ STOCK SIZE ______ SUPPLIER ______

CHEMICAL ANALYSIS

HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo						

GRAIN SIZE ______ HARDENABILITY ______

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

S/N OR LOT NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ______

THIS CERTIFICATION COVERS ______ PIECES ON OUR SHIPPER ______ DATED ______

INCLUDING ______

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

SIGNED ______

TITLE ______

INSPECTION REPORT

DIE NO.

1ST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

LAST PC. INSPECTION

CI ACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

FINAL INSPECTION

CHARACTERISTICS	ACTUAL DIM.'S	% CHECK	METHOD OF INSPECTION	TEMPLATE INSP. DATE	ACCEPT	REJECT	DATE	REMARKS

I RDNESS VERIFICATION	IDENTIFICATION
215	

ARC-210A

NATIONAL TESTING LABORATORIES
13220½ South Western Avenue
Gardena, California 90247
323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUSTOMER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

	YIELD				ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONG. IN 4D	ELONG. %	RED OF AREA DIM.	RED OF AREA AREA %
XIMUMS										
IIMUMS										

IELD at .2% offset

In our opinion, the material
the requirements of the Specification.

Arcturus MANUFACTURING CORPORATION
6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-2"A"
FORGINGS - ARCTURUS X-292-MP-1000

INDUCER TURBO-PUMP

ANSC P/N 1138579-1"C"
ARCTURUS DIE X-292

AUGUST 10, 1971

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MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-2 "A"
FORGINGS - ARCTURUS X-292-MP-1000

INDUCER TURBO-PUMP

ANSC P/N 1138579-1 "C"
ARCTURUS DIE X-292

AUGUST 10, 1971

PREPARED BY C. J. O[illegible] APPROVED BY E B Blake

DATE 8/12/71 DATE 8/13/71

Orbitrus MFG. CORP. OXNARD, CALIF.	REVISIONS	X-292-MP-1000
	INDUCER TURBO-PUMP ANSC P/N 1138579-1 "C" ANSC 90297-2 "A"	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

MFG. CORP.
OXNARD, CALIF.

TABLE OF CONTENTS

ANSC-TC-1000	
ISSUED	8/10/71
REVISION	N/C
PAGE	1 of 1

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following parts:

ANSC P/N	Arcturus Die #
1138579-1 "C"	X-292
1138579-2 "C"	X-293
1138575-1 "D"	2915
1138576-1 "E"	2916
1138577-1 "D"	2917
1138578-1 "E"	2918

2.0 REFERENCE DOCUMENTS: ANS-90295A, AMS 2249, ANS 90296, ANS 9032, MIL-I-6866, MIL-I-8950, FED-STD-184, MIL-STD-129.

3.0 MELTING PRACTICE: Material shall be produced by multiple melting useing the consumable electrode practice with both melting cycles performed under vacuum conditions.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent Min.	Percent Max.
Aluminum	4.70	5.60
Tin	2.00	3.00
Iron		0.25
Oxygen		0.12
Manganese		0.03
Carbon		0.05
Nitrogen		0.04
Hydrogen		0.0125
Other elements, each 1/		0.05
Other elements, total 1/		0.20
Titanium		Remainder

1/ Need Not Be Reported

SECTION 1: REQUIREMENTS

5.0 MATERIAL: The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

6.0 PRIMARY MELTING CYCLE:

6.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

6.2 Water Leakage: There shall be no water leakage during the melting operation.

6.3 Power Control: There shall be no power interruption other than momentary interruptions due to transient arch characteristics during melting.

7.0 SECONDARY MELTING CYCLE:

7.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

7.2 Water Leakage: There shall be no water leakage during or after the melting period.

7.3 Power Control: There shall be no interruption of power during the melting cycle, except the gradual power reduction required to control the size and shape of shrinkage cavity.

8.0 WELDING:

8.1 Welding Process: All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

8.2 Preparation of Electrodes: Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

9.0 CLEANING AND COATING: The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass shot) shall not be used for cleaning the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

10.0 PROPERTIES: The ingot, assembled and melted as specified in 3.0 shall be worked, pressed, forged or swaged, as required, to obtain minimum billet grain size.

10.1 Macrograin Size: Macrograin size for bars and billets shall be 0.25 inch maximum. Variation of macrograin sizes shall not be banded or grouped with predominant grain size variation limited to 0.125 inch.

11.0 DIMENSIONS AND TOLERANCES: Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

12.0 SURFACE QUALITY: The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subject to particle impact cleaning.

13.0 INTERNAL QUALITY: The material shall be uniform in quality and condition,

and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No. 3) flat-bottomed hole single point indication on the full metal thickness.

14.0 IDENTIFICATION: The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

SECTION 2: QUALITY ASSURANCE PROVISIONS

15.0 SUPPLIER RESPONSIBILITY:

15.1 Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC).

15.2 Procedures and Instructions: The supplier shall provide processing procedures or instructions to insure compliance with these requirements, copies of which shall be submitted to ANSC for review and approval prior to processing. These procedures or instructions shall be in sufficient detail so as to enable future reporducibility of material to the same processes. Copies of these procedures or instructions and records of conformance shall be retained for a period of seven years and identifiable to the specific ANSC purchase order.

15.3 Reports: Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. The reports shall include at least the following information:

(a) Raw material certifications for alloying materials (aluminum and tin).

(b) Certification to specification ANS-90296.

(c) Macrostructure photographs and macrograin size determinations, each bar and billet.

(d) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity

not in excess of normal mill practice).

(e) Chemistry, representing billets identified relative to ingot location.

(f) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(g) All information required in 14.0

(h) Processing procedures.

16.0 LOT: A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

17.0 VERIFICATION:

17.1 Material: The processing procedures supplied as specified in 15.2 shall be reviewed to assure compliance with material requirements of 5.0.

17.2 Chemical Composition: A chemical analysis shall be made from bars or billets in accordance with AMS-2249 and shall conform to requirements of 4.0

17.3 Heats: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

17.4 Welding: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

17.5 Cleaning: The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 9.0.

17.6 Properties: The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 10.0.

17.7 Dimensions and Tolerances: Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

17.8 Penetrant Inspection: Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method C using penetrant containing sulfur and chlorine not exceeding 50 parts per million (PPM).

17.9 Microstructure and Workmanship:

17.9.1 Macroetch Sample Preparation and Inspection: The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 1 requirements.

17.10 Ultrasonic Inspection: Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of the lathe turned billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of the bars while the bar is simultaneously turning and the carriage carrying the inspection head is traveling along the axial length of the bar. Inspection shall be performed in accordance with MIL-I-8950, except that, when the instrument is set so that the first back-reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, the material shall be inspected for loss of back reflection. Any loss in back reflection in excess of 50 percent of full saturation of the screen shall be considered not acceptable.

17.10.1 Noise Level: The noise level for each bar and billet shall be recorded and reported.

17.10.2 Calibration Standard: The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a depth of 0.250 inches.

17.10.3 Procedures: The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

17.10.4 Rework: Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

17.11 Identification: Bars and billets shall be visually inspected to verify conformance to Section 1 requirements.

SECTION 3 PREPARATION FOR DELIVERY

18.0 PACKAGING: Each product shall be packaged to prevent damage during handling and shipping.

18.2 Marking: Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number

SECTION 4 NOTES

19.0 INTENDED USE: Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90°F to -423°F.

19.1 Ordering Data: Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
    (1) Source surveillance
    (2) Source acceptance
    (3) Source inspection - Government.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE Forging Furnace Control ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ANSC-FC-1000 ISSUED 8/10/71 REVISION N/C PAGE 1 of 1

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the parts for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus Furnace #25, a gas fired furnace with two zone control, shall be utilized in heating the subject parts for forging. Burners are L&N Speed-O-Max controllers-recorders, with series 60 controllers. N.A. flat flame-excess air types.

3.1 Temperature control on Furnace #25 is maintained by 2 Ray-O-Tube thermo-piles, located at the front and rear of the furnace.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800°F., and temperature uniformity throughout the furnace shall not exceed ± 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

1.0 ACKNOWLEDGEMENT & SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #25, as described in Arcturus procedure ANSC-FC-1000, shall have controls set at 1775 deg. F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature through-out shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure.

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

6.0 LOADING OF CROSS WORKED MULTIPLES: Cross worked multiples shall be loaded in accordance with the following procedure.

6.1 Crossworked multiples shall be loaded in serial number sequence.

6.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

7.0 LOADING OF PARTIALLY FINISHED FORGINGS: Partially finished forgings shall be loaded in accordance with the following procedure:

7.1 Partially finished forgings shall be loaded in serial number sequence.

7.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

8.0 RECORD OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

9.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 25,000# Erie steam hammer for all forging operations. Cross forging shall be performed utilizing a set of flat dies. Prefinishing and finishing operations shall be performed utilizing dies per Arcturus die drawings.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Cross Working: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000 shall be manually transferred, utilizing hand tongs, from furnace #25 and placed on flat dies installed in the 25,000# hammer. Cross working shall then be performed.

5.2 Prefinishing: Cross worked pieces, reheated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in dies conforming to Arcturus die drawings. The pieces shall be located in the die and the first hammer blow shall be made, without any lubricant, to set the piece in position. Subsequent blows shall be made utilizing a graphite impregnated oil lubricant flowed on the dies. The hammerman shall control the intensity of the blows by observing the flow of metal in the die, so that more heat is not generated in the piece than is dissipated between blows. Adiabatic heating will result in an unsatisfactory micro-structure. Forging shall cease when it is observed that the last blow has produced no flow of metal. The hazard of inducing surface or interior cracks emanates at this point.

5.3 Finishing: Prefinished forgings heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in finish dies conforming to Arcturus die drawings. The same precautions and procedures outlined under prefinishing above, shall be observed. Cooling after the final hammer operation shall be performed by quenching in water.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. Procedure if Cracking Occurs: The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

ARCTURUS MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-HT-1000
	Heat Treat Procedure Vacuum Annealing Procedure ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000. This procedure shall apply to the following parts.

ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1 E	2918

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, ANSC 90297 A.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Vacuum annealing equipment and controls shall be as follows:

4.1 IPSEN electrically heated furnace with 48" x 60" retort chamber.

4.2 Honeywell Control Pyrometer #A0275789015.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25^{O}F of the 1400^{O}F temperature used as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in a retort of adequate size for the load. A vacuum of 0.1 micron or less is pulled on the retort and the retort is heated to 1400^{O}F $\pm$ 25^{O}F. Time at temperature shall be one (1) hour minimum. Furnace shall then be cooled to 300^{O}F. maximum and final cooling to room temperature shall be in air. Temperature profile verification on actual parts shall be by recorded chart by thermocouple in contact with one part in the load.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS H[illegible]AT [illegible]REAT AN[illegible] VE[illegible] RECORD.

H. T. V[illegible]NDO[illegible] ________ [illegible]TE________ A C P. O.________ [illegible] DR.#________

MATER[illegible] ________ A[illegible] ________ [illegible]________

CHAR[illegible] ________ T[illegible] IN FURN[illegible] ________

TIME OUT [illegible] ________ T[illegible] OF [illegible] ________

[illegible] ________ S/N [illegible] ________

ALL [illegible] IN [illegible] ONLY. RETURN CHART WITH FO[illegible].

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, ANSC 90297 A, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000, in accordance with the following procedure.

3.1 Mechanical Property Requirements: Four test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 ± 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
110,000	100,000	12	25

3.2 Microstructure: Examination for microstructure shall be in accordance with paragraph 3.7.2 of ANSC 90297A. The microstructure shall indicate that the forgings have been finished forged at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transus has been applied. The microstructure shall be uniform and indicate a wrought structure.

3.3 Macrostructure: Examination for macrostructure shall be in accordance with paragraph 3.7.3 of ANSC 90297 A. The macrostructure shall show no evidence of gross alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of ANSC 90297 A. These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{0}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 <u>PRODUCT EVALUATION SHALL BE AS FOLLOWS:</u>

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 <u>ACCEPTANCE STANDARDS:</u>

6.1 <u>Class:</u> The following class shall apply.

6.1.1 <u>Class AAA:</u>

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 <u>Rejection Criteria:</u>

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in 6.6.2.

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 <u>Material Disposition Control:</u>

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol having a 1/2 inch diameter center or a having 1/2 inch maximum dimensions. The

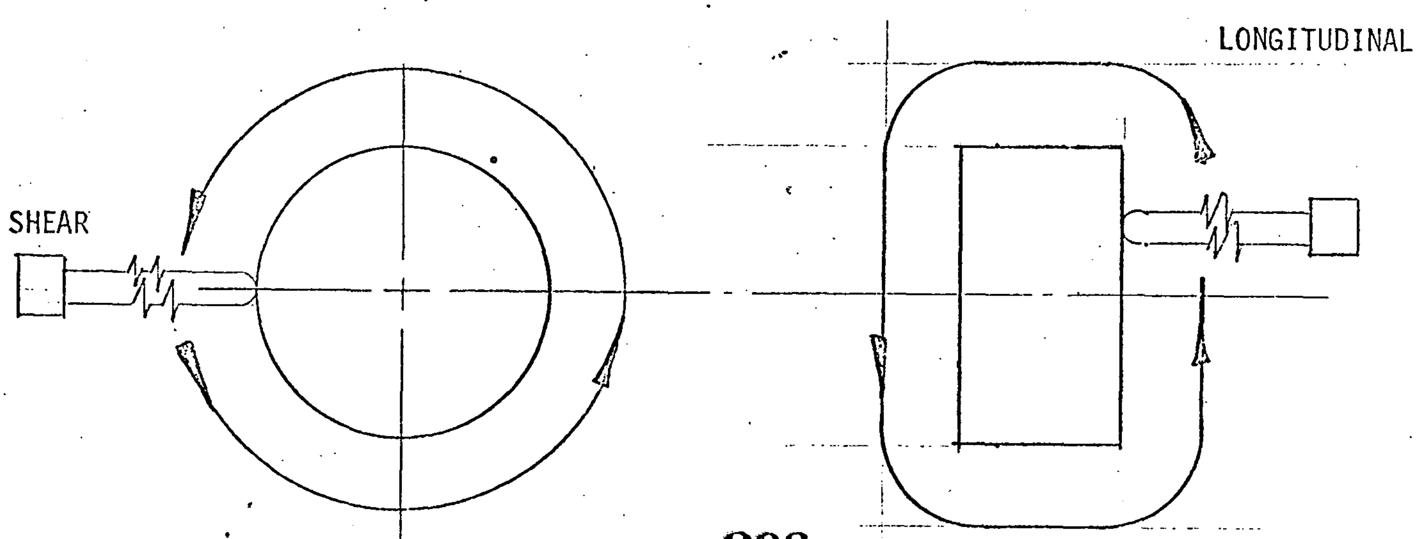
center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual.



MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FPPI-1000
	Penetrant Inspection Procedure for ANSC 5AL-2.5 SN ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: MIL-I-6866B, AMend #1, Amend #2, ANSC 90297A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS: Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ______ W. O. NO. ______

CONTACT ______ DATE ______

P. O. NO. ______ ACK. ______

QTY. ______ CODE ______

PART NO. ______ REV. ______

PRICE

DELIVERY REQUIRED ______ UNIT ______

______ SET UP ______

DELIVERY QUOTED ______ TOOLS ______

______ SPECIAL ______

PROCESSING	SPECIFICATION	NOTES
MATERIAL		
HEAT TREAT		
ULTRASONIC		
X-RAY		
ZYGLO		
MAGNAFLUX		
CLEAN		
ROUGH MACHINE		
FIN MACHINE		
TESTING		
TEST BARS		

GOV. ______ COMM. ______ CONTRACT ______

SPECIAL INSTRUCTIONS ______

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

		QTY.	PRICE - UNIT	AMOUNT
MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
HEAT TREAT				
NORMALIZE				
ANNEAL				
BRINELL	CERT ☐			
NORM & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP.	☐			
			TOTAL	

OPERATION		EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

FOOTAGE DMS WT.	ROUGH STOCK SIZE
DATE STOCK ORDERED:	
DATE STOCK DUE IN:	
IN STOCK	

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

239

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

ARCTURUS MFG. CORP.

DATE ____________

Arcturus MANUFACTURING CORPORATION

No. 5670 A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ______________________ PURCHASE ORDER ______________

MATERIAL ______________ HEAT NO. ______________ BAR SIZE ______________

DATE RECEIVED ______________ TOTAL BARS REC'D ________ PAGE NO. ________ OF ________

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

CONSUMPTION

Job	$
Qty.	Lbs.

____
RECEIVED BY

ALLOCATION				WITHDRAWALS				
Cut #	Length Weight	JOB NO.		Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				1				
2				2				
3				3				
4				4				
5				5				
6				6				
7				7				
8				8				
9				9				
10				10				
11				11				
12				12				
13				13				
14				14				
15				15				
16				16				
17				17				
18				18				
19				19				
20				20				
21				21				
22				22				
23				23				
24				24				
25				25				
26				26				
27				27				
28				28				

ARCTURUS MFG. CORP. OXNARD, CALIF	ARCTURUS FURNACE LOADING LOG	F-1001 ISSUED 3-4-67 REVISION PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ______________ PART NO. ______________ P. O. ______________

MATERIAL ______________ SPEC. ______________ STOCK SIZE ______________ SUPPLIER ______________

CHEMICAL ANALYSIS															
HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo							

GRAIN SIZE ______________ HARDENABILITY ______________

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

S/N OR LOT NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ______________

THIS CERTIFICATION COVERS ______________ PIECES ON OUR SHIPPER ______________ DATED ______________

INCLUDING ______________

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

SIGNED ______________

TITLE ______________

INSPECTION REPORT

DIE NO.

1ST PC. INSPECTION

HARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

LAST PC. INSPECTION

HARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

FINAL INSPECTION

ARACTERISTICS	ACTUAL DIM.'S	% CHECK	METHOD OF INSPECTION	TEMPLATE INSP. DATE	ACCEPT	REJECT	DATE	REMARKS

PROCESS VERIFICATION

IDENTIFICATION

NATIONAL TESTING LABORATORIES

13220½ South Western Avenue
Gardena, California 90247
323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUST[illegible]ER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

	YIELD				ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONG. IN 4D	ELONG. %	RED OF AREA DIM.	RED OF AREA AREA. %
[illegible]IMUMS										
[illegible]										

[illegible]IELD at .2% offset

In our opinion, the material
244 the requirements of the Specification.

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-2"A"
FORGINGS - ARCTURUS X-293-MP-1000

INDUCER TURBO-PUMP

ANSC P/N 1138579-2"C"
ARCTURUS DIE X-293

AUGUST 10, 1971

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC 90297-2"A"
FORGINGS - ARCTURUS X-293-MP-1000

INDUCER TURBO-PUMP

ANSC P/N 1138579-2"C"
ARCTURUS DIE X-293

AUGUST 10, 1971

Prepared by C. J. Arnold Approved by E B Bl[illegible]

Date 8/12/71 Date 8/13/71

Oxnard MFG. CORP. OXNARD, CALIF.	REVISIONS	X-293-MP-1000
	INDUCER, TURBO-PUMP ANSC P/N 1138579-2"C" ANSC 90297-2"A"	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

MFG. CORP. OXNARD, CALIF.	TABLE OF CONTENTS	ANSC-TC-1000
		ISSUED 8/10/71
		REVISION N/C
		PAGE 1 of 1

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following parts:

ANSC P/N	Arcturus Die #
1138579-1 "C"	X-292
1138579-2 "C"	X-293
1138575-1 "D"	2915
1138576-1 "E"	2916
1138577-1 "D"	2917
1138578-1 "E"	2918

2.0 REFERENCE DOCUMENTS: ANS-90295A, AMS 2249, ANS 90296, ANS 9032, MIL-I-6866, MIL-I-8950, FED-STD-184, MIL-STD-129.

3.0 MELTING PRACTICE: Material shall be produced by multiple melting useing the consumable electrode practice with both melting cycles performed under vacuum conditions.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent Min.	Percent Max.
Aluminum	4.70	5.60
Tin	2.00	3.00
Iron		0.25
Oxygen		0.12
Manganese		0.03
Carbon		0.05
Nitrogen		0.04
Hydrogen		0.0125
Other elements, each 1/		0.05
Other elements, total 1/		0.20
Titanium		Remainder

1/ Need Not Be Reported

SECTION 1: REQUIREMENTS

5.0 MATERIAL: The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

6.0 PRIMARY MELTING CYCLE:

6.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

6.2 Water Leakage: There shall be no water leakage during the melting operation.

6.3 Power Control: There shall be no power interruption other than momentary interruptions due to transient arch characteristics during melting.

7.0 SECONDARY MELTING CYCLE:

7.1 Vacuum Control: The vacuum level shall not exceed 1000 microns.

7.2 Water Leakage: There shall be no water leakage during or after the melting period.

7.3 Power Control: There shall be no interruption of power during the melting cycle, except the gradual power reduction required to control the size and shape of shrinkage cavity.

8.0 WELDING:

8.1 Welding Process: All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

8.2 Preparation of Electrodes: Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

9.0 CLEANING AND COATING: The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass shot) shall not be used for cleaning the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

10.0 PROPERTIES: The ingot, assembled and melted as specified in 3.0 shall be worked, pressed, forged or swaged, as required, to obtain minimum billet grain size.

10.1 Macrograin Size: Macrograin size for bars and billets shall be 0.25 inch maximum. Variation of macrograin sizes shall not be banded or grouped with predominant grain size variation limited to 0.125 inch.

11.0 DIMENSIONS AND TOLERANCES: Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

12.0 SURFACE QUALITY: The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subject to particle impact cleaning.

13.0 INTERNAL QUALITY: The material shall be uniform in quality and condition,

and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No. 3) flat-bottomed hole single point indication on the full metal thickness.

14.0 IDENTIFICATION: The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

SECTION 2: QUALITY ASSURANCE PROVISIONS

15.0 SUPPLIER RESPONSIBILITY:

15.1 Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC).

15.2 Procedures and Instructions: The supplier shall provide processing procedures or instructions to insure compliance with these requirements, copies of which shall be submitted to ANSC for review and approval prior to processing. These procedures or instructions shall be in sufficient detail so as to enable future reporducibility of material to the same processes. Copies of these procedures or instructions and records of conformance shall be retained for a period of seven years and identifiable to the specific ANSC purchase order.

15.3 Reports: Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. The reports shall include at least the following information:

(a) Raw material certifications for alloying materials (aluminum and tin).

(b) Certification to specification ANS-90296.

(c) Macrostructure photographs and macrograin size determinations, each bar and billet.

(d) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity

not in excess of normal mill practice).

(e) Chemistry, representing billets identified relative to ingot location.

(f) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(g) All information required in 14.0

(h) Processing procedures.

16.0 LOT: A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

17.0 VERIFICATION:

17.1 Material: The processing procedures supplied as specified in 15.2 shall be reviewed to assure compliance with material requirements of 5.0.

17.2 Chemical Composition: A chemical analysis shall be made from bars or billets in accordance with AMS-2249 and shall conform to requirements of 4.0

17.3 Heats: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

17.4 Welding: The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

17.5 Cleaning: The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 9.0.

17.6 Properties: The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 10.0.

17.7 Dimensions and Tolerances: Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

17.8 Penetrant Inspection: Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method C using penetrant containing sulfur and chlorine not exceeding 50 parts per million (PPM).

17.9 Microstructure and Workmanship:

17.9.1 Macroetch Sample Preparation and Inspection: The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 1 requirements.

17.10 Ultrasonic Inspection: Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of the lathe turned billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of the bars while the bar is simultaneously turning and the carriage carrying the inspection head is traveling along the axial length of the bar. Inspection shall be performed in accordance with MIL-I-8950, except that, when the instrument is set so that the first back-reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, the material shall be inspected for loss of back reflection. Any loss in back reflection in excess of 50 percent of full saturation of the screen shall be considered not acceptable.

17.10.1 Noise Level: The noise level for each bar and billet shall be recorded and reported.

17.10.2 Calibration Standard: The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a depth of 0.250 inches.

17.10.3 Procedures: The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

17.10.4 Rework: Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

17.11 Identification: Bars and billets shall be visually inspected to verify conformance to Section 1 requirements.

SECTION 3 PREPARATION FOR DELIVERY

18.0 PACKAGING: Each product shall be packaged to prevent damage during handling and shipping.

18.2 Marking: Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number

SECTION 4 NOTES

19.0 INTENDED USE: Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90°F to -423°F.

19.1 Ordering Data: Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
    (1) Source surveillance
    (2) Source acceptance
    (3) Source inspection - Government.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FC-1000
	Forging Furnace Control ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71
		REVISION N/C
		PAGE 1 of 1

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the parts for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus Furnace #25, a gas fired furnace with two zone control, shall be utilized in heating the subject parts for forging. Burners are L&N Speed-O-Max controllers-recorders, with series 60 controllers. N.A. flat flame-excess air types.

3.1 Temperature control on Furnace #25 is maintained by 2 Ray-O-Tube thermo-piles, located at the front and rear of the furnace.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800°F., and temperature uniformity throughout the furnace shall not exceed ± 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

1.0 ACKNOWLEDGEMENT & SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #25, as described in Arcturus procedure ANSC-FC-1000, shall have controls set at 1775 deg. F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature through-out shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure.

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

6.0 LOADING OF CROSS WORKED MULTIPLES: Cross worked multiples shall be loaded in accordance with the following procedure.

6.1 Crossworked multiples shall be loaded in serial number sequence.

6.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F1001.

7.0 LOADING OF PARTIALLY FINISHED FORGINGS: Partially finished forgings shall be loaded in accordance with the following procedure:

7.1 Partially finished forgings shall be loaded in serial number sequence.

7.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

8.0 RECORD OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

9.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 25,000# Erie steam hammer for all forging operations. Cross forging shall be performed utilizing a set of flat dies. Prefinishing and finishing operations shall be performed utilizing dies per Arcturus die drawings.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Cross Working: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000 shall be manually transferred, utilizing hand tongs, from furnace #25 and placed on flat dies installed in the 25,000# hammer. Cross working shall then be performed.

5.2 Prefinishing: Cross worked pieces, reheated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in dies conforming to Arcturus die drawings. The pieces shall be located in the die and the first hammer blow shall be made, without any lubricant, to set the piece in position. Subsequent blows shall be made utilizing a graphite impregnated oil lubricant flowed on the dies. The hammerman shall control the intensity of the blows by observing the flow of metal in the die, so that more heat is not generated in the piece than is dissipated between blows. Adiabatic heating will result in an unsatisfactory micro-structure. Forging shall cease when it is observed that the last blow has produced no flow of metal. The hazard of inducing surface or interior cracks emanates at this point.

5.3 Finishing: Prefinished forgings heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000, shall be manually transferred from furnace #25 and placed in finish dies conforming to Arcturus die drawings. The same precautions and procedures outlined under prefinishing above, shall be observed. Cooling after the final hammer operation shall be performed by quenching in water.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. Procedure if Cracking Occurs: The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-HT-1000
	Heat Treat Procedure Vacuum Annealing Procedure ANSC 5AL-2.5 Sn ELI Forgings ANSC 90297 A	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000. This procedure shall apply to the following parts.

ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1 E	2918

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, ANSC 90297 A.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Vacuum annealing equipment and controls shall be as follows:

4.1 IPSEN electrically heated furnace with 48" x 60" retort chamber.

4.2 Honeywell Control Pyrometer #A0275789015.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25^{o}F of the 1400^{o}F temperature used as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in a retort of adequate size for the load. A vacuum of 0.1 micron or less is pulled on the retort and the retort is heated to 1400^{o}F $\pm$ 25^{o}F. Time at temperature shall be one (1) hour minimum. Furnace shall then be cooled to 300^{o}F. maximum and final cooling to room temperature shall be in air. Temperature profile verification on actual parts shall be by recorded chart by thermocouple in contact with one part in the load.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS HEAT TREAT AND VERIFICATION RECORD.
H. T. VENDOR ________ DATE ________ ARC P. O. ________ [illegible] DR. ________
MATERIAL ________ ARC DIE ________ FURNACE ________
CHART SPEED, /HR. ________ TIME IN FURNACE ________
TIME OUT OF FURNACE ________ T. P. OF [illegible] ________
OPERATOR [illegible] ________ S/N OF POS. ________
ALL ITEMS [illegible] BE FILLED IN [illegible] INK ONLY. RETURN CHART WITH FORM [illegible].

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, ANSC 90297 A, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000, in accordance with the following procedure.

3.1 Mechanical Property Requirements: Four test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 $\pm$ 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
110,000	100,000	12	25

3.2 Microstructure: Examination for microstructure shall be in accordance with paragraph 3.7.2 of ANSC 90297A. The microstructure shall indicate that the forgings have been finished forged at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transus has been applied. The microstructure shall be uniform and indicate a wrought structure.

3.3 Macrostructure: Examination for macrostructure shall be in accordance with paragraph 3.7.3 of ANSC 90297 A. The macrostructure shall show no evidence of gross alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of ANSC 90297 A. These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{o}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 PRODUCT EVALUATION SHALL BE AS FOLLOWS:

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 ACCEPTANCE STANDARDS:

6.1 Class: The following class shall apply.

6.1.1 Class AAA:

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 Rejection Criteria:

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in 6.6.2.

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 Material Disposition Control:

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol having a 1/2 inch diameter center or a having 1/2 inch maximum dimensions. The

center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

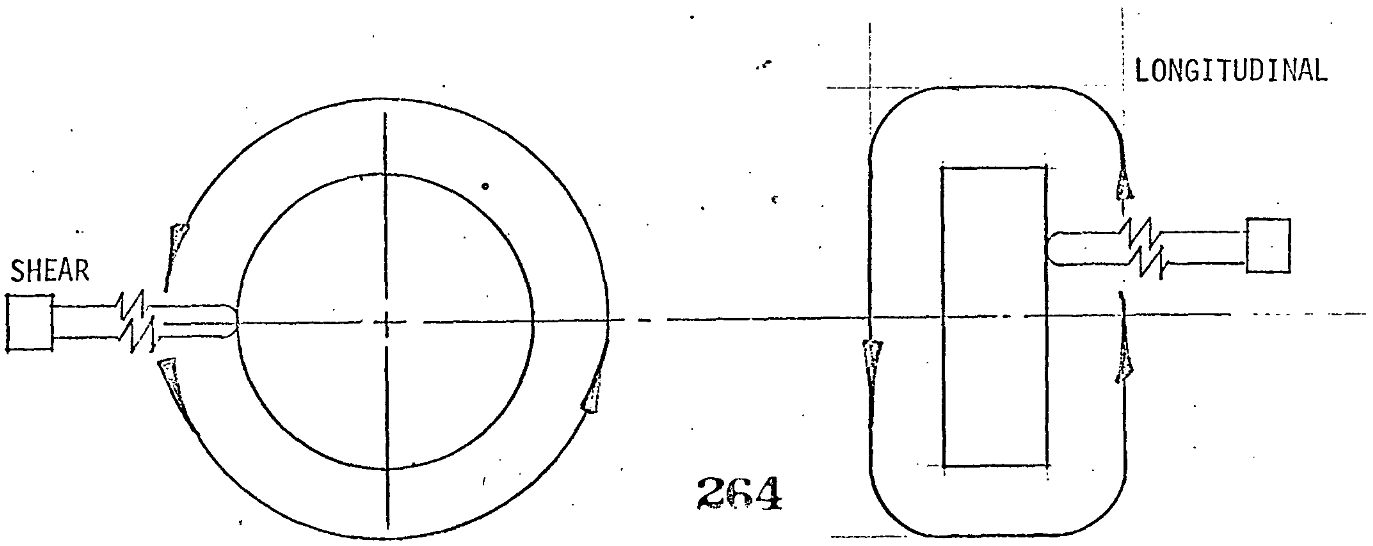
8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

ARCTURUS MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	X293-SP-1000
	Scan Plan for ANSC P/N 1138579-20 Arcturus X-293	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual.



1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: MIL-I-6866B, AMend #1, Amend #2, ANSC 90297A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS: Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ______________________ W. O. NO. ______________________

CONTACT ______________________ DATE ______________________

P. O. NO. ______________________ ACK. ______________________

QTY. ______________________ CODE ______________________

PART NO. ____________ REV. ____________

PRICE

DELIVERY REQUIRED ______________________ UNIT ______________________

______________________ SET UP ______________________

DELIVERY QUOTED ______________________ TOOLS ______________________

______________________ SPECIAL ______________________

PROCESSING	SPECIFICATION	NOTES
MATERIAL		
HEAT TREAT		
ULTRASONIC		
X-RAY		
ZYGLO		
MAGNAFLUX		
CLEAN		
ROUGH MACHINE		
FIN MACHINE		
TESTING		
TEST BARS		

GOV. ____________ COMM. ____________ CONTRACT ______________________

SPECIAL INSTRUCTIONS ______________________

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

	OPERATION	EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

		QTY.	PRICE - UNIT	AMOUNT
MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
HEAT TREAT				
NORMALIZE				
ANNEAL				
BRINELL	CERT ☐			
NORM & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP.	☐			
			TOTAL	

FOOTAGE

DMS WT.

ROUGH STOCK SIZE

DATE STOCK ORDERED:

DATE STOCK DUE IN:

IN STOCK

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

ARC 210

ARCTURUS MFG. CORP.

DATE ____________

Arcturus MANUFACTURING CORPORATION

No. 5674 A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ____________ PURCHASE ORDER ____________

MATERIAL ____________ HEAT NO. ____________ BAR SIZE ____________

DATE RECEIVED ____________ TOTAL BARS REC'D ____________ PAGE NO. ________ OF ________

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

ALLOCATION				WITHDRAWALS				
Cut #	Length Weight	JOB NO.		Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				1				
2				2				
3				3				
4				4				
5				5				
6				6				
7				7				
8				8				
9				9				
10				10				
11				11				
12				12				
13				13				
14				14				
15				15				
16				16				
17				17				
18				18				
19				19				
20				20				
21				21				
22				22				
23				23				
24				24				
25				25				
26				26				
27				27				
28				28				

CONSUMPTION

Job	$
Qty.	Lbs.

____
RECEIVED BY

ARCTURUS MFG. CORP. OXNARD, CALIF	ARCTURUS FURNACE LOADING LOG	F-1001
		ISSUED 3-4-67
		REVISION
		PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ______________________ PART NO. ______________________ P. O. ______________________

MATERIAL ______________________ SPEC. ______________________ STOCK SIZE ______________ SUPPLIER ______________________

CHEMICAL ANALYSIS

HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo						

GRAIN SIZE ______________________ HARDENABILITY ______________________

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

S/N OR LOT NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ______________________

THIS CERTIFICATION COVERS ______________ PIECES ON OUR SHIPPER ______________ DATED ______________

INCLUDING ______________________

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

SIGNED ______________________

TITLE ______________________

INSPECTION REPORT

DIE NO.

1ST PC. INSPECTION

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

[illegible]

CHARACTERISTICS	ACTUAL DIM.		METHOD OF INSPECTION	ACCEPT	REJECT	DATE		REMARKS

FINAL INSPECTION

CHARACTERISTICS	ACTUAL DIM.'S	% CHECK	METHOD OF INSPECTION	TEMPLATE INSP. DATE	ACCEPT	REJECT	DATE	REMARKS

HARDNESS VERIFICATION	IDENTIFICATION
271	

RC-210A

NATIONAL TESTING LABORATORIES
13220½ South Western Avenue
Gardena, California 90247
323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUST[illegible]ER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

	YIELD				ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONG. IN 4D	ELONG. %	RED OF AREA DIM.	RED OF AREA AREA. %
[illegible]XIMUMS										
[illegible]NIMUMS										

[illegible]IELD at .2% offset

In our opinion, the material
272
the requirements of the Specification.

Arcturus MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030

MANUFACTURING PROCEDURES
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC AMS 5737D
FORGING - ARCTURUS X-294-MP-1000

STATOR, TURBINE,
SECOND STAGE-FORGING

ANSC P/N 1138580 "E"
ARCTURUS DIE X-294

AUGUST 10, 1971

MANUFACTURING PROCEDURES,
CONTROLS AND DOCUMENTATION FORMS
FOR PROCESSING ANSC AMS 5737D
FORGINGS - ARCTURUS X294-MP-1000

STATOR, TURBINE,
SECOND STAGE-FORGING

ANSC P/N 1138580 "E"
ARCTURUS DIE X-294

AUGUST 10, 1971

PREPARED BY [illegible] APPROVED BY [illegible]

DATE 8/12/71 DATE 9/13/71

MFG. CORP. OXNARD, CALIF.	REVISIONS	X294-MP-1000
	STATOR, TURBINE, SECOND STAGE ANSC P/N 1138580-1 "E" AMS 5737D	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1. SCOPE: This revision page shall cover changes applicable to the above part.

DATE	PAGE	Spec/Form #	Revisions

Ovatus MFG. CORP. OXNARD, CALIF.	TABLE OF CONTENTS	ANSC-TC-1000 ISSUED 8/10/71 REVISION N/C PAGE 1 of 1

ARCTURUS MFG. CORP. OXNARD, CALIF.	ARCTURUS MATERIAL SPECIFICATION	ANSC-MS-1000-1
	Raw Material Procurement ANSC A286 Forging AMS 5737D	ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1.0 SCOPE: This specification shall apply to material utilized in the forging of the following part:

ANSC P/N	Arcturus Die #
1138580-1"E"	X-294

2.0 REFERENCE DOCUMENTS: AMS 5737D, AMS 2248, AMS 2241.

3.0 MELTING PRACTICE: Material shall be consumable electrode melted.

4.0 COMPOSITION: Composition of material shall be as follows:

Element	Percent Min.	Percent Max.
Carbon	-	0.08
Manganese	-	2.00
Silicon	-	1.00
Phosphorus	-	0.025
Sulfur	-	0.025
Chromium	13.50	16.00
Nickel	24.00	27.00
Molybdenum	1.00	1.50
Titanium	1.90	2.35
Boron	0.0030	0.010
Vanadium	0.10	0.50
Aluminum	-	0.35

5.0 TENSILE PROPERTIES: Tensile test properties from a sample of the bar material; forged to a test coupon, followed by heat treatment as in paragraph 6.0, and tested at room temperature, shall conform to the following properties:

Tensile strength, psi - 140,000 min.
Yield strength at 0.2% - offset or at 0.0105 in. in 2 in. extension under load (E=29,100,000) psi - 95,000 min.
Elongation, % in 2 in. or 4D - 12 min.
Reduction of area (round specimen) % - 15 min.

5.1 Stress Rupture Properties: This requirement is deleted by note 17 of drawing 1138580-1"E".

6.0 HEAT TREATMENT: Test specimens, prior to test, shall be solution heat treated at 1650°F ± 25°F, holding at heat for 2 hours and quenching in water, and then shall be precipitation heat treated by heating to 1325°F ± 25°F, holding at heat for 16 hours, and then air cooling.

7.0 REJECTIONS: Material not conforming to this specification will be subject to rejection.

1.0 SCOPE: This procedure shall be followed in utilizing equipment for heating the part for forging referenced on the title page.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-6875D.

3.0 IDENTIFICATION OF EQUIPMENT: Arcturus furnace #12, a gas fired furnace, shall be utilized in heating the subject part for forging.

3.1 Temperature control on Furnace #12 is maintained by a L&N Speed-O-Max controller-recorder, with a series 60 controller.

4.0 RESPONSIBILITY: The responsibility for conducting the necessary furnace calibration and surveys, together with routine chart and battery replacement, shall rest with the Quality Control Department.

5.0 TEMPERATURE UNIFORMITY: The furnace and controlling instruments, shall be calibrated at 1800 deg. F., and temperature uniformity throughout the furnace shall not exceed $\pm$ 20 deg. F. The furnace shall be surveyed at thirty (30) day intervals. Suitable labels showing date, furnace number, company certifying, and individual certifying, shall be placed on each instrument at the time of survey.

6.0 CERTIFICATION: Certification of the above shall be maintained on record at Arcturus.

1.0 ACKNOWLEDGMENT AND SCOPE: This procedure shall be followed in heating multiples for forging after release and transfer of the multiples per Arcturus Process Procedure ANSC-MS-1000-1.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual. Arcturus Form #F-1001.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the heating practice in accordance with this procedure.

4.0 FURNACE CONTROL: Furnace #12, as described in Arcturus Procedure ANSC-FC-1001-1 shall have controls set at 2050°F.

4.1 Furnace Uniformity: Before loading of multiples, furnace temperature must even out. Uniform temperature shall be achieved.

5.0 LOADING OF MULTIPLES: Cut multiples shall be loaded in accordance with the following procedure:

5.1 Multiples shall be loaded in serial number sequence.

5.2 A record of loading sequence shall be maintained on Arcturus furnace loading form #F-1001.

6.0 RECORDING OF DATA: In addition to the data maintained on furnace loading form F-1001, the job number, together with the serial numbers of each part, shall be entered on each furnace chart. The date also shall be entered on each chart.

7.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace loading charts and recorder charts, will be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 ACKNOWLEDGMENT & SCOPE: The following procedure shall be followed in forging the above parts.

2.0 REFERENCE DOCUMENT: Arcturus Quality Assurance Manual.

3.0 RESPONSIBILITY: It shall be the responsibility of the forge shop superintendent to carry out the forging practice according to this procedure.

4.0 EQUIPMENT: Equipment utilized shall consist of a 12,000# steam hammer for all forging operations.

5.0 FORGING: Forging shall be performed in accordance with the following procedure:

5.1 Pancaking: Multiples heated in accordance with the practice outlined in Arcturus Process Procedure ANSC-FH-1000-1 shall be manually transferred, utilizing hand tongs, from furnace #12 and placed on flat dies installed in the 12,000# hammer. Pancaking shall then be performed to generate shape of such size to guarantee dimensions shown on Arcturus drawing X-294.

6.0 PROCEDURES APPLICABLE TO ALL OPERATIONS:

6.1 Reheating: Heat lot and bar lot variations in raw material preclude any exact definition of the number of hammer blows and the number of reheats to complete a part. The heater shall restamp while hot the serial number of each part after each forging operation. When the part fills the cavity of the die, the hammer operation shall be considered complete.

6.2. Procedure if Cracking Occurs: The hammerman shall visually inspect the part when it is taken out of the dies. Any hairline cracks require the part to be sent to inspection so that these cracks do not propagate into sound metal. If cracking is observed while the part is being forged in the die, forging shall stop, and the part shall be sent to process grinding for removal of the cracks.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE Heat Treat Procedure ANSC A286 Forging AMS 5737 D	ANSC-HT-1000-1 ISSUED 8/10/71 REVISION N/R PAGE 1 of 1

1.0 ACKNOWLEDGMENT & SCOPE: This procedure shall be followed in heat treating finish forged parts after forging and processing per Arcturus Process Procedure ANSC-FP-1000-1. This procedure shall apply to the following part:

ANSC P/N	Arcturus Die #
1138580-1 E	X-294

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, MIL-H-81200, AMS 5737D.

3.0 RESPONSIBILITY: It shall be the responsibility of the heat treat processor to carry out the heat treating practice according to this procedure.

4.0 EQUIPMENT: Equipment and controls shall be as follows:

4.1 Solution Heat Furnace: Arcturus furnace #50-1 with L&N Speed-O-Max controllers and recorders with series 60 controllers. Two zone (front and rear) control. Flat flame excess air burners.

4.2 Precipitation Heat Treat Furnace: Arcturus furnace #25E with four zone control by Honeywell Brown Electronik Strip recorder-controllers, model 153R10PS 141-20A4. Four (4) Chromel-Alumel thermocouples are located in the roof of the furnace. Overheat protection control is maintained by one (1) Honeywell Brown Electrik 4-point strip recorder-controller, model #15X60P4-W7-32A4.

5.0 TEMPERATURE UNIFORMITY: Temperature uniformity shall be within $\pm$ 25°F of the temperatures involved as determined by periodic 30 day surveys.

6.0 PROCEDURE: Parts shall be placed in furnace #50-1, after furnace has attained a uniform temperature of 1650°F and held at heat for 2 hours. Parts shall then be water quenched. Parts shall then be placed in furnace #25E and aged at 1325°F for 16 hours, and subsequently air cooled.

7.0 RECORDING OF DATA: In addition to the data maintained on the heat treat vendors work order, the following information is to be supplied on the furnace chart.

ARCTURUS [illegible] RECORD
H. T. VENDOR ________ DATE ________ A.C.P.O. ________ [illegible] DR.# ________
MATERI[illegible] ________ [illegible] ________ [illegible] ________
CHAR[illegible] ________ [illegible] ________
TIME OUT [illegible] ________ [illegible] ________
[illegible] ________ S/N [illegible] ________
ALL [illegible] ONLY. RETURN CHART
WITH [illegible].

8.0 VERIFICATION OF COMPLIANCE: All recorded data, including furnace charts, shall be forwarded to Arcturus Quality Control for verification of compliance to this procedure.

1.0 SCOPE: This procedure shall apply to the testing of the parts referenced on the title page of this manual.

2.0 REFERENCE DOCUMENTS: Arcturus Quality Assurance Manual, AMS 5737D, ASTM E8, FED-STD-151.

3.0 PRE-PRODUCTION QUALIFICATIONS: After forging design and procedures have been established, one forging from each of the parts referenced on the title page shall be destructively tested, after heat treatment per ANSC-HT-1000-1. in accordance with the following procedure.

3.1 Mechanical Property Requirements: Three test blanks shall be cut from the locations designated on the ANSC drawings for each of the parts referenced on the title page of this document. After machining the bars and tensile testing at a strain rate of 0.005 ± 0.002 inches per inch per minute through the yield strength, and then increasing the strain rate so as to produce failure in approximately one additional minute, the following minimum properties shall apply in all directions.

U.S. psi	Y.S. psi	%E	%R.A.
140,000 Min.	95,000 Min.	12	15 Min.

3.2 Microstructure: Examination of microstructure shall be in accordance with note #16 of drawing #1138580 E and shall reveal no evidence of a duplex microstructure, nor any ~~bonding~~ banding. Grain size shall be ASTM-E113 size 5 or finer.

3.3 Macrostructure: Macrostructure examination on a cut face of the examined forging shall show no predominant grain flow in any one direction and no evidence of alloy segregation.

4.0 PRODUCTION TESTING: Production testing of each part shall include the requirements of paragraph 3.1 above. The requirements of paragraph 3.2 and 3.3 shall not apply.

5.0 REPORTS: Test results as obtained above shall be reported to Aerojet on Arcturus Form #19829. Three copies of this document shall be furnished to Aerojet attesting to conformance of AMS 5737 "D". These reports shall include the purchase order number, specification number and mill heat number and location and orientation by S/N of each forging with respect to its bar.

6.0 REJECTIONS: Forgings not conforming to this specification or to authorized modifications shall be subject to rejection.

1.0 This procedure describes in detail the process of ultrasonic inspection of the parts referenced on the title page of this procedure.

2.0 Equipment shall be as follows:

a. Sperry Type UM 721-10N instrument
b. Automation Industries lithium sulfate transducers.
c. Water tank and water filter.
d. Test blocks, Alcoa series, with the following hole sizes and metal travel distances. (for qualification of equipment)

Hole Sizes	Metal Travel Distances
2/64"	6", 3", 3/4", 1/2", 1/4"
4/64	3"

e. Test blocks, 4340 material, with the following hole sizes and metal travel distances. (for scanning of parts)

Hole Sizes	Metal Travel Distances
3/64", 5/64"	1/8", 1/4", 1/2", 3/4", 1", 1 1/4", 1 1/2", 1 3/4"

3.0 Equipment qualification shall be as follows:

a. Resolve a 2/64" flat bottomed hole at the following frequencies and metal travel distances. (a) 0.75" at 2.25 MC, (b) 0.50" at 5 MC, (c) 0.25" at 10 MC.

b. Determine the resolution of a 2/64" flat bottomed hole with a 3/4" transducer and an incident angle of 0^{0}. Adjust the flat bottomed hole response for an amplitude of 50% saturation. With this condition, a minimum of 40% of saturation of the flat bottomed hole indication shall be separated and clearly distinguishable from the front surface indication. Resolve a 2/64 inch flat bottomed hole at a metal travel of 6 inches, indicating a minimum response of 50% saturation so that base line noise level shall not exceed 5% of the amplitude of the flat bottomed hole response. A minimum signal change of 50% of saturation shall be demonstrated between response from a 2/64 inch and a 4/64 inch flat bottomed hole at a metal travel of three inches.

4.0 Parts inspected shall be scanned using the following procedure. Both longitudinal and shear wave techniques shall be used.

a. Care shall be exercised to maintain surfaces free of grease, oil, paint or any other contaminants. Surface finish shall be 125 RMS maximum.

b. In standardizing the instrument for the search scan, a 2/64" flat bottomed hole with a metal travel distance of 1/2", shall be displayed at an amplitude of 50% of full scale deflection (approx. 1").

c. In scanning the part, crystal overlap shall be maintained at 3/16" maximum. Scanning speed shall be maintained at one inch per second maximum. Parts shall be scanned in accordance with the scan plan. Water travel distance from the transducer to part undergoing test shall be adjusted so that the second front reflection does not appear between the first front and first back reflection. Maintain the same water-travel distance for both standardization and inspection procedures within plus or minus 1/2".

5.0 PRODUCT EVALUATION SHALL BE AS FOLLOWS:

a. Use reference blocks of the same material, shape, and condition as the parts being inspected.

b. Match as closely as possible the response of the flaw to that of one of the above blocks. Diameter and depth may not be determined within the limits of the blocks.

6.0 ACCEPTANCE STANDARDS:

6.1 Class: The following class shall apply.

6.1.1 Class ~~AAA:~~ AA

6.1.1.1 No flaw indications exceeding 25% of the response from a 3/64 inch diameter flat bottomed hole are acceptable.

6.1.1.2 Flaw indications in excess of 10% of the response from a 3/64 inch diameter flat bottomed hole shall not have their centers closer than 1 inch.

6.1.1.3 No drop in back reflection of 20% or greater than cannot be be attributed to surface condition or abnormal test condition is acceptable.

6.2 Rejection Criteria:

6.2.1 Material exhibiting flaws in excess of above requirements for the applicable class shall be rejected except as described in 6.6.2.

6.2.2 Flaws in excess of the acceptance limits shall be allowed if it is definitely established that they will be completely removed by future machining or cutting operations.

6.3 Material Disposition Control:

6.3.1 Rejected material shall be handled by the MRB system.

7.0 MARKING: All defects shall be located on the part with a symbol having a 1/2 inch diameter center or a having 1/2 inch maximum dimensions. The

center of the mark is to be as close as possible, coincident with the projected center of the defect, and the depth from the surface shall be shown adjacent to the mark. Acceptable parts shall be stamped with an A-4 stamp.

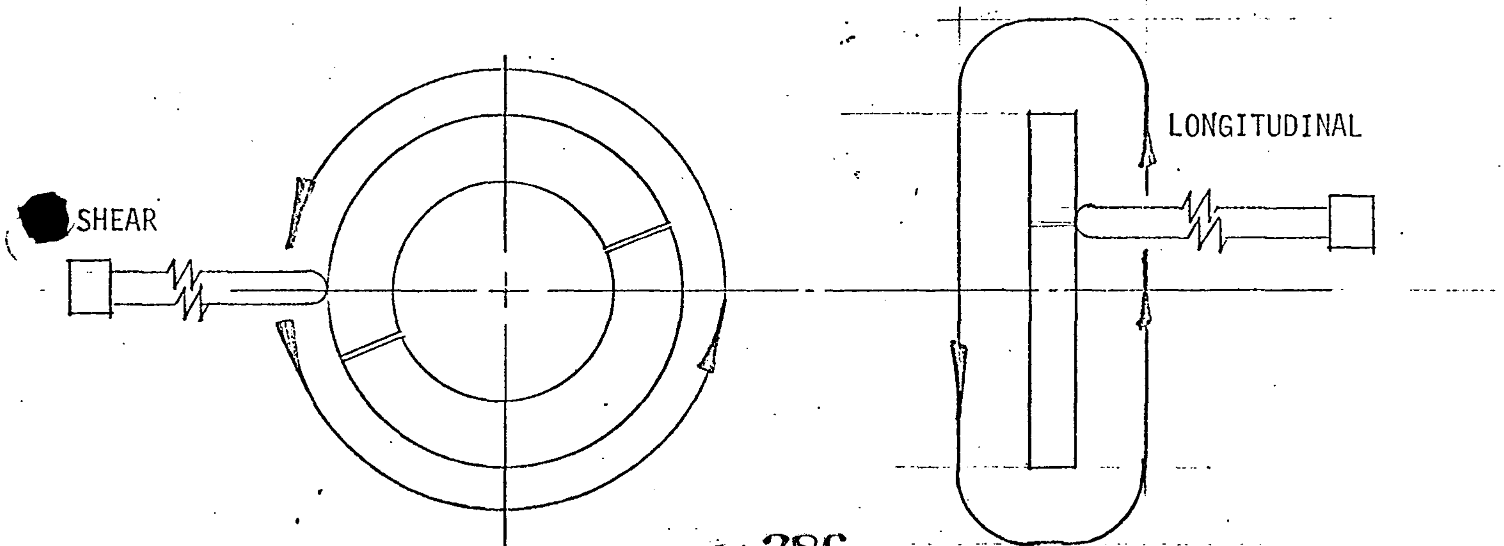
8.0 PRIMARY STANDARDS: Instruments and gauges shall be periodically tested for accuracy and shall have properly stamped labels attached to them showing date of last inspection and date of next inspection.

9.0 REFERENCE DOCUMENTS: MIL-I-8950B.

Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	X294-SP-1000
	Scan Plan for ANSC P/N 1138580-1E Arcturus X-294	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: The following illustration shows the scan plan to be used in ultrasonic inspection of the above part.

2.0 INSPECTION: Inspection shall be performed according to section ANSC-UIP-1000 of this manual.



Arcturus MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-FPPI-1000-1
	Penetrant Inspection Procedure for ANSC A286 Forging AMS 5737 D	ISSUED 8/10/71
		REVISION N/R
		PAGE 1 of 1

1.0 SCOPE: This procedure shall apply to the penetrant inspection of the parts referenced on the title page of this document.

2.0 REFERENCE DOCUMENTS: Mil-I-6866B, Amend #1, Amdnd #2, ANSC 90297 A, Arcturus Quality Assurance Manual, ANSC 9032-1.

3.0 PROCEDURE: Parts shall be inspected in accordance with Type 1, Method B of MIL-I-6866B.

3.1 Precleaning: Parts shall be precleaned in accordance with paragraph 5.2 of MIL-I-6866B.

3.2 Penetrant Application: Penetrant shall be applied by dipping in accordance with paragraph 5.3 of MIL-I-6866B.

3.3 Emulsifier Application: Emulsifier shall be applied in accordance with paragraph 5.4.2 of MIL-I-6866B.

3.4 Rinsing: All parts shall be rinsed in accordance with paragraph 5.5 of MIL-I-6866B.

3.5 Developing: All parts shall be developed in accordance with paragraph 5.6.1 of MIL-I-6866B.

3.6 Drying: After development per 3.5 above, parts shall be dried in accordance with paragraph 5.7 of MIL-I-6866B.

3.7 Inspection: Inspection shall be in accordance with paragraph 5.8 of MIL-I-6866B.

3.8 Final Cleaning: Parts shall be steam cleaned after all of the above processes have been completed.

4.0 ACCEPTANCE STANDARDS:

Acceptance standards shall be per applicable drawing and purchase order requirements.

ADDRESS ______________________ W. O. NO. ______________________

CONTACT ______________________ DATE ______________________

P. O. NO. ______________________ ACK. ______________________

QTY. ______________________ CODE ______________________

PART NO. ______________ REV. ________

DELIVERY REQUIRED ______________________

____

DELIVERY QUOTED ______________________

____

PRICE

UNIT ______________________

SET UP ______________________

TOOLS ______________________

SPECIAL ______________________

PROCESSING	SPECIFICATION	NOTES
MATERIAL ______	______	______
HEAT TREAT ______	______	______
ULTRASONIC ______	______	______
X-RAY ______	______	______
ZYGLO ______	______	______
MAGNAFLUX ______	______	______
CLEAN ______	______	______
ROUGH MACHINE ______	______	______
FIN MACHINE ______	______	______
TESTING ______	______	______
	______	______
TEST BARS ______	______	______
	______	______

GOV. __________ COMM. __________ CONTRACT ______________________

SPECIAL INSTRUCTIONS ______________________

____

____

____

____

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

	OPERATION	EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

		QTY.	PRICE - UNIT	AMOUNT
MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
HEAT TREAT				
NORMALIZE				
ANNEAL				
BRINELL	CERT ☐			
NORM & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP. ☐				
			TOTAL	

FOOTAGE

DMS WT.

ROUGH STOCK SIZE

DATE STOCK ORDERED:

DATE STOCK DUE IN:

IN STOCK

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

Arcturus MANUFACTURING CORPORATION

DATE ____________

No. 5678 A

– PRESS HARD USE BALL POINT PEN ONLY –

SUPPLIER ____________ PURCHASE ORDER ____________

MATERIAL ____________ HEAT NO. ____________ BAR SIZE ____________

DATE RECEIVED ____________ TOTAL BARS REC'D ____________ PAGE NO. ________ OF ________

BAR NO.	LENGTH	WEIGHT

Prepare one of these packages for each bar received on all materials except 4000 Series and Aluminum.

Prepare one package for each shipment received of 4000 Series and Aluminum.

RECEIVER OR CUTTER

Return this package to Metallurgical Dept. immediately after receiving or cutting.

ALLOCATION				WITHDRAWALS				
Cut #	Length Weight	JOB NO.		Cut #	Length Weight	JOB NO.	DATE	INITIAL
1				1				
2				2				
3				3				
4				4				
5				5				
6				6				
7				7				
8				8				
9				9				
10				10				
11				11				
12				12				
13				13				
14				14				
15				15				
16				16				
17				17				
18				18				
19				19				
20				20				
21				21				
22				22				
23				23				
24				24				
25				25				
26				26				
27				27				
28				28				

CONSUMPTION

Job	$
Qty.	Lbs.

____
RECEIVED BY

ARCTURUS MFG. CORP. OXNARD, CALIF		F-1001
	ARCTURUS FURNACE LOADING LOG	ISSUED 3-4-67
		REVISION
		PAGE

JOB. NO.	DATE	TYPE MATERIAL	FURNACE	FURNACE TEMP.

SERIAL NO.	TIME IN	TIME OUT	TIME IN	TIME OUT	TIME IN	TIME OUT

ARC Form #F-1001

MANUFACTURING CORPORATION

6001 ARCTURUS AVENUE • OXNARD, CALIFORNIA 93030 • TEL. (805) 488-4481 • TWX (805) 447-7107

TEST CERTIFICATE

CUSTOMER ____________ PART NO. ____________ P. O. ____________

MATERIAL ____________ SPEC. ____________ STOCK SIZE ____________ SUPPLIER ____________

CHEMICAL ANALYSIS

HEAT NUMBER		C	Mn	P	S	Si	Cr	Mo						

GRAIN SIZE ____________ HARDENABILITY ____________

FORGINGS PROCESSED AS FOLLOWS:

PROCESSING SPECIFICATIONS

MECHANICAL PROPERTIES

[illegible]N OR [illegible]T NO.	YIELD STRENGTH	ULTIMATE STRENGTH	ELONG. (4D)	RED. OF AREA (%)	REMARKS

FORGINGS IDENTIFIED WITH ____________

THIS CERTIFICATION COVERS ____________ PIECES ON OUR SHIPPER ____________ DATED ____________

INCLUDING ____________

I HEREBY CERTIFY THAT THE PARTS WERE PROCESSED IN ACCORDANCE WITH THE SPECIFICATIONS NOTED. ORIGINAL COPIES OF ALL CERTIFICATES ARE ON FILE AT ARCTURUS MANUFACTURING CORPORATION.

SIGNED ____________

TITLE ____________

QUALITY CONTROL

WORK ORDER NO.	DATE
CUSTOMER	
CUST. P.O. NO.	DEL. DATE
PART NO.	QTY.
DIE NO.	

OPERATION		EST.	ACT	SCHEDULE DATE	COMPLETE DATE
1	CUT STEEL				
2	SET-UP				
3	FORGE				
4					
5	RESTRIKE				
6	GRIND				
7	STRAIGHTEN				
8	PUNCH OUT				
9	CLEAN				
10					
11	BLOCK				
12	TURRET LATHE				
13	ENGINE LATHE				
14	MILLING				
15	DRILL PRESS				
16	PUNCH PRESS				
17	BROACH				
18	CLEAN				
19	HEAT TREAT				
20	MAG. INSPECT				
21	INSPECT				
22	SHIP				
23					
24					
25	MISC.				

OVERSHIPMENT ALLOWANCE

UNDERSHIPMENT ALLOWANCE

DATE	INVOICE NO.	PCS. SHIPPED	BALANCE

MAT. SPEC.				
PRIORITY				
GOV'T. CONTRACT				
		QTY.	PRICE - UNIT	AMOUNT
HEAT TREAT				
NORMALIZE				
ANNEAL				
[illegible]	CERT ☐			
[illegible] & TEMP.				
GRIND.				
ZYGLO				
SAND BLAST				
MAG. INSP.	CERT ☐			
NAVY INSP. ☐				
			TOTAL	

FOOTAGE	ROUGH STOCK SIZE
DMS WT.	
DATE STOCK ORDERED:	
DATE STOCK DUE IN:	
IN STOCK	

NET WT.

CUT

RATE

DIE NO.

REMARKS

LEAD CAST DUE

LEAD CAST APPROVED

OTHER DATA

ARC 210

ARCTURUS MFG. CORP.

ACME TESTING LABORATORIES
13220½ South Western Avenue
Gardena, California 90247
323-6184

CERTIFIED REPORT OF PHYSICAL TEST IN ACCORDANCE WITH FEDERAL TEST METHOD, STANDARD 151

CUSTOMER:

DATE OF REPORT:
OUR CONTROL NO.:
CUSTOMER P.O. NO.:
CUSTOMER SHIPPER NO.:
OUR SHIPPER NO.:
SERVICES:

CUSTOMER'S IDENTIFYING INFORMATION:
MATERIAL:
SPECIFICATION:
HEAT NO.:
CUSTOMER:
PART NO.:
SERIAL NO.:
DIE NO.:
OTHER:

PHYSICAL PROPERTIES

	YIELD				ULTIMATE					
	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.I.	ELONG. IN 4D	ELONG. %	RED OF AREA DIM.	RED OF AREA AREA, %
…IMUMS										
…IMUMS										

…LD at .2% offset

In our opinion, the material ... the requirements of the Specification.

N8300R:72-103
May 1972

ENCLOSURE 1

SPECIFICATION ANS-90296B, TITANIUM SPONGE

Enclosure 1

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET - GENERAL

POST OFFICE BOX 13070 • SACRAMENTO, CALIFORNIA 95813
CODE IDENT 34632

SPECIFICATION ANS-90296B

TITANIUM SPONGE

SUPERSEDING:		
AGC- ANS-90296 DATE 12-28-70	AGC- DATE	AGC- DATE

RELEASES (REPLACE PAGES IN SPECIFICATION WITH LATEST CHANGE BELOW)

REV LTR	RELEASE DATE	PAGE NUMBERS 1	2	3	4	5	6	7	8	9	10	PAGE ADDITIONS
	12-28-70	-	-	-	-	-	-	-	-	-	-	
A	1-21-71	A		A	A	A	A	A	A	A	A	
B	11-29-71			B	B	B	B	B				

Authorized for release:

ANSC Specifications and Standards

ANSC #2 - IC (10/70)

Section 1. SCOPE

1.1 Scope.- This specification establishes the requirements for virgin titanium metal melting stock commonly designated as titanium sponge.

1.2 Classification.- The titanium sponge shall be classified as follows:

-1	Magnesium reduced and finished by distillation
-2	Magnesium reduced and finished by leaching or inert gas sweep
-3	Sodium-reduced and finished by leaching

Each classification shall be called out by referencing the specification number, plus the suffix number designating the classification desired.

Section 2. APPLICABLE DOCUMENTS

2.1 Government Documents.- Unless otherwise specified, the following documents, listed in the issue of the Department of Defense Index of Specifications and Standards in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage

(Copies of documents required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards).

2.2 Other Documents.- Unless otherwise specified, the following documents, of the issue in effect on date of invitation for bids, shall form a part of this specification to the extent specified herein.

PUBLICATION

American Society for Testing and Materials

ASTM E 10	Brinell Hardness of Metallic Materials
ASTM E 120	Chemical Analysis of Titanium and Titanium Base Alloys
ASTM C 357	Bulk Density of Granular Refractory Materials

(Copies may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia 3, Pennsylvania).

Section 3. REQUIREMENTS

(A) 3.1 Material.- Titanium sponge shall be prepared by reduction of titanium tetrachloride or an Aerojet Nuclear Systems Company (ANSC) approved alternate process. The metal shall be supplied in irregular shaped lumps of approximately 0.5 inch or less in size.

(B) 3.2 Density.- The density of the titanium sponge lumps shall be from 50 to 75 pounds per cubic foot.

(A) 3.3 Contaminants.- The titanium sponge shall be made from virgin material and shall be free from scrap or contaminants. The metal shall be supplied in uniform well-mixed blends.

(A) 3.4 Chemical Composition.- The chemical composition of the metal shall be as specified in Table I.

TABLE I

CHEMICAL COMPOSITION REQUIREMENTS

	Weight by Percent		
	ANS-90296-1	ANS-90296-2	ANS-90296-3
Element			
Nitrogen, max	0.015	0.015	0.010
Carbon, max	0.020	0.025	0.020
Sodium, max (total)			0.19
Magnesium, max	0.08	0.50	
(B) Chlorine, max	0.12	0.20	0.20
Iron, max	0.12	0.10	0.05
Silicon, max	0.04	0.04	0.04
Hydrogen, max	0.005	0.03	0.05
Oxygen, max	0.10	0.10	0.10
All other impurities (total), max	0.05	0.05	0.05
Titanium, balance (nominal)	99.40	98.89	99.24

3.5 Hardness.- The average hardness value shall not exceed HB 120.

Section 4. QUALITY ASSURANCE PROVISIONS

4.1 Supplier Responsibility.-

4.1.1 Inspection.- Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC). The method of verification shall be in accordance with Table II.

4.1.2 Processes.- The supplier shall prepare or have processing, inspection and testing procedures that will be used to insure compliance of the specific requirements and controls set forth in this specification and to enable future reproducibility of the material in the same manner. These procedures shall provide for controls that will detect anomalies that will not be revealed in subsequent inspections or testing. Copies of all procedures and instructions or records of conformance, including the supplier's internal restricted, private and proprietary procedures representing the processes used shall be approved by an ANSC representative and retained for a period of seven
(B) (7) years. They shall be identifiable to the specific ANSC purchase order, specification and lot number.

The supplier shall submit to the ANSC buyer at least ten (10) days prior to their anticipated use copies of procedures and instructions for review to assure that the specific requirements of this specification are included. The procedures submitted may reference any internal restricted, private or proprietary procedures identified by the seller's control number, name and date.

ANSC directed drawing, specification and purchase order change notices shall be incorporated in previously approved procedures and instructions.

(B) 4.1.3 Reports.- Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests, verifying conformance to the requirements of this specification. Separate reports shall be submitted for each lot of material. These reports shall include at least the following information.

(a) Certification that manufacturing, processing, inspection and tests were performed in accordance to procedures transmitted and on file at the seller's facility listing any revisions and deviations thereto.

(b) Inspection and test reports for 3.2, 3.4 and 3.5.

(c) Certification of conformance to 3.3.

(d) Certification of conformance to 4.3 identifying the sampling method.

(B) 4.2 Lot.- A lot shall consist of all the titanium sponge output from one or more refinement cycles blended and submitted for inspection at one time.

(A) 4.3 Sampling.- The following methods, or an ANSC approved alternate, shall be acceptable for sampling the lot to determine conformance to the chemical and physical requirements.

4.3.1 Method A.- The sample shall be obtained by random selection and shall provide a 0.50 percent sample but not less than 30 pounds. The blended evaluation sample shall be split to produce five or more samples, 50 grams or more each, to be melted into buttons, and one sample of at least 1 pound to be compacted and sampled by drilling for the analysis of magnesium, sodium, chlorine, and hydrogen. The buttons shall be melted in a furnace under an inert-gas atmosphere. The resulting buttons shall be checked for Brinell hardness and samples shall be taken from each button for the required analysis.

4.3.2 Method B.- The sample shall be obtained by random selection and shall provide a 0.50 percent sample but not less than 30 pounds. The blended evaluation sample shall be compacted into an consumable electrode for melting. A portion of the compact shall be cut off prior to melting and sampled by drilling for the analysis of magnesium, sodium, chlorine, and hydrogen. The electrode shall be melted under an inert atmosphere or in a vacuum to form an ingot. The resulting ingot shall be sampled by cutting a transverse section approximately 0.5 in. thick-from the center of the ingot. After machining both sides of this slab, five chemical analyses and five Brinell hardness readings shall be made at locations equal distances apart and diagonally across the machined surface. Slices approximately 0.25 in. wide shall be taken from this slab, parallel to the hardness locations, to obtain samples weighing approximately 0.1 gram for oxygen and nitrogen analysis. One half of the slab shall accompany the shipment and the other half shall be retained by the supplier.

4.3.3 Alternate.- Alternate procedures for sampling, if used, shall be submitted for ANSC review and approval at least ten (10) days prior to their anticipated use.

4.4 Verification.-

(A) 4.4.1 Material.- The processing procedures supplied as specified in 4.1.3 shall be reviewed to assure compliance with the material requirements of 3.1. All lots of material produced shall be made to the set of procedures approved by the procuring agency.

4.4.2 Density.- The density shall be determined in accordance with ASTM C 357 or ANSC approved alternate method.

(A) 4.4.3 Contaminants.- Sponge lots shall be 100 percent visually and fluoroscopically inspected for high and low density contaminants and other undesirable foreign materials.

4.4.4 Chemical Analysis.- The samples as specified in 4.3 shall be analyzed for chemistry in accordance with ASTM E 120 or ANSC approved alternate method.

4.4.5 Hardness.- The Brinell hardness of a sample shall be the average of the hardness determinations made on the solid samples prepared as specified in 4.3. The method of measurement shall be in accordance with ASTM E 10 using a 10-mm ball, 1500-kg load, and a 30 second dwell.

Section 5. PREPARATION FOR DELIVERY

5.1 Packaging.- Pack titanium sponge in air-tight moisture-proof sealed metal cans or drums.

5.2 Marking.- Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name

(b) The number of this specification and applicable suffix number (see 1.2)

(c) The material identification

(d) The lot number and its chemical composition

(e) The purchase order number

Section 6. NOTES

6.1 Intended Use.- Material produced to this specification is intended for use in critical, cryogenic rocket vehicle requiring high reliability and operating in the temperature range of +90°F to -423°F.

(A) 6.2 Ordering Data.- Procurement documents should specify the following information:

(a) This specification number and applicable suffix number (see 1.2).

(b) Quality Control Standard Clauses

(1) Source surveillance

(2) Source acceptance

(3) Source inspection - Government

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TABLE II

VERIFICATION CROSS REFERENCE INDEX

	Section 3 Requirement Paragraph	Verification											Section 4 Verification Method Paragraph
		Method											
		Not Applicable	Inspection	Analysis	Demonstration	Test							
(A)	3.1		X	X									4.4.1
(A)	3.2			X		X							4.4.2
(A)	3.3		X			X							4.4.3
(A)	3.4			X		X							4.4.4
(A)	3.5			X		X							4.4.5

Enclosure (2)

REVIEW OF ANS-90296A

DOCUMENT TITLE: TITANIUM SPONGE

Comment No.	Comment By	Page	Paragraph Table, Figure	Comments (Include Justification Traceability)	Disposition (for Spec Group use)

306

AEROJET NUCLEAR SYSTEMS COMPANY
A DIVISION OF AEROJET-GENERAL

DOCUMENT APPROVAL SIGNATURE SHEET

TYPE OF DOCUMENT	DOCUMENT NO.
MATERIAL SPECIFICATION	ANS-90296B

TITLE

TITANIUM SPONGE

PREPARED BY	ORGANIZATION	EXTENSION
P. P. Dessau	N8130	6568

APPROVAL SIGNATURE	ORGANIZATION	DATE
F. E. Porter, Manager Quality Engineering Section	N7000	11/24/71
N. A. Edlebeck, Manager Turbopump Department	N8300	11/29/71
T. A. Redfield, Manager Materials Section	N8130	11/23/71

ANSC 81, 20 (12/70)

N8300R:72-103
May 1972

ENCLOSURE 2

SPECIFICATION ANS-90295B,
TITANIUM ALLOY 5Al-2.5 Sn ELI BARS AND BILLETS

308

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET - GENERAL

POST OFFICE BOX 13070 • SACRAMENTO, CALIFORNIA 95813
CODE IDENT 34632

SPECIFICATION ANS-90295B

TITANIUM ALLOY 5AL-2.5SN ELI BARS AND BILLETS

SUPERSEDING:

AGC- ANS-90295 DATE 12-28-70	AGC- DATE	AGC- DATE

RELEASES (REPLACE PAGES IN SPECIFICATION WITH LATEST CHANGE BELOW)

REV LTR	RELEASE DATE	PAGE NUMBERS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	PAGE ADDITIONS
	12-28-70	-	-	-	-	-	-	-	-	-	-	-	-	-					
A	1-21-71	A	A		A	A	A	A	A	A	A	A	A	A					
B	11-29-71	B	B	B	B	B	B		B	B	B	B	B	B	B			B	

Authorized for release:

ANSC Specifications and Standards

ANSC 82-1C (10/70)

Section 1. SCOPE

1.1 This specification sets forth requirements for an Extra Low Interstitial (ELI) grade of titanium alloy, 5Al-2.5Sn, in bar and billet form.

(B) 1.1.1 For purposes of this specification bars and billets are semi-finished material forms used in subsequent forging processes. Billets 4 inches in diameter or less shall be referred to as bars.

Section 2. APPLICABLE DOCUMENTS

(A) 2.1 Government Documents.- Unless otherwise specified, the following documents, listed in the issue of the Department of Defense Index of Specifications and Standards in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-I-6866	Inspection, Penetrant, Method of
MIL-I-8950	Inspection, Ultrasonic, Wrought Metals, Process for

STANDARDS

Federal

FED-STD-184	Identification Marking of Aluminum, Magnesium, and Titanium

Military

MIL-STD-129	Marking for Shipment and Storage

2.2 Aerojet Nuclear Systems Company Documents.- Unless otherwise specified, the following documents of the issue in effect on date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

ANS-90296	Titanium Sponge
ANS-9032	Quality Standards for Wrought and Forged Products

Section 3. REQUIREMENTS

3.1 Material.- The ingot used for production of bars and billets shall be composed of pure, virgin master alloying materials and titanium sponge conforming to ANS-90296. No scrap (internally generated or otherwise) shall be used in the production of material supplied to this specification.

3.2 Chemical Composition.- Bars and billets shall conform to the chemical composition specified in Table I.

TABLE I

CHEMICAL COMPOSITION

	Element	Percent
	Aluminum	4.70 - 5.60
	Tin	2.00 - 3.00
	Manganese	0.03 max.
	Iron	0.25 max.
(B)	Oxygen	0.10 max.
	Carbon	0.05 max.
(B)	Nitrogen	0.02 max.
	Hydrogen	0.0125 max.
	Other Elements, each (1)	0.05 max.
	Other Elements, total (1)	0.20 max.
	Titanium	Remainder

(1) Need not be reported

(A) 3.3 Heats.- Bars and billets shall be made from ingots which have been vacuum melted at least twice by the consumable electrode process. The melting operation shall be controlled as specified in 3.3.1 and 3.3.2.

3.3.1 Primary Melting Cycle.-

(B) 3.3.1.1 Vacuum Control.- The vacuum level shall not exceed 6000 microns.

3.3.1.2 Water Leakage.- There shall be no water leakage during the melting operation.

(A) 3.3.1.3 Power Control. - There shall be no power interruption other than momentary interruptions due to transient arc characteristics during melting.

3.3.2 Secondary Melting Cycle.-

(B) 3.3.2.1 Vacuum Control.- The vacuum level shall not exceed 1000 microns during the steady state portion of the melt.

3.3.2.2 Water Leakage.- There shall be no water leakage during or after the melting period.

(B) 3.3.2.3 Power Control.- There shall be no power interruptions in excess of 5 seconds during the normal final melting cycle, except for the gradual power reduction required to control the size and shape of shrinkage cavity.

3.4 Welding.-

3.4.1 Welding Process.- All welding processes needed to assemble the electrode shall be performed in an inert atmosphere using welding methods which preclude the possibility of contaminating the electrode (ingot) with high density welding electrode debris (such as tungsten inclusions), slag and oxides.

3.4.2 Preparation of Electrodes.- Welding on the electrodes for the final melt cycle shall be limited to the welding of the stub to the ingot. The stub shall not be used for the production of billets nor shall the stub weld be melted during the secondary melt.

(A) 3.5 Cleaning and Coating.- The cast electrode shall be cleaned between the primary and secondary melting cycles to insure that undesirable surface features remaining on the electrode are removed. Cleaning may be accomplished by water spray and pickling methods. Abrasives (such as sand, metal or glass
(B) shot) shall not be used for cleaning or cutting the electrode. A suitable coating shall be applied to the ingot for primary ingot reduction.

(B) 3.6 Properties.- The ingot, assembled and melted as specified in 3.3, shall be worked, pressed, forged or swaged, as required, to optimize billet micro and macrostructure.

(B) 3.6.1 Macrograin Size.- Macrograin size for bars and billets shall be 0.25 inch maximum. The macrostructure shall be uniform and free of banding.

(B) 3.6.2 Microstructure.- The microstructure of bars and billets shall show no evidence of having been heated above the beta transus temperature. The microstructure shall consist predominantly of equiaxed, primary alpha with no evidence of transformation products (phases).

(A) 3.7 Dimensions and Tolerances.- Dimensions and tolerances shall be as specified in the contract or order. The billet shall be furnished round with a maximum diameter of eight inches.

(A) 3.8 Surface Quality.- The bars and billets shall be free from surface imperfections as determined by penetrant inspection. The acceptance level shall conform to ANS-9032-1. Surfaces to be penetrant inspected shall not be subjected to particle impact cleaning.

(A) 3.9 Internal Quality.- The material shall be uniform in quality and condition, and free from porosity, cracks, pipe, high or low density inclusions and any evidence of enfoliations. Ultrasonic inspection acceptance criterion shall be 3/64 inch (No. 3) flat bottomed hole single point indication on the full metal thickness.

3.10 Identification.- The material shall be identified in accordance with FED-STD-184 and shall include the following, in the order listed:

(a) Alloy identification
(b) Ingot number
(c) Bar or billet location
(d) Bar or billet serial number
(e) Name or trade mark of manufacturer
(f) Purchasers name or trade mark
(g) Purchase order or contract number

Section 4. QUALITY ASSURANCE PROVISIONS

4.1 Supplier Responsibility.-

4.1.1 Inspection.- Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein and may use any facilities acceptable to the Aerojet Nuclear Systems Company (ANSC). The method of verification shall be in accordance with Table II.

4.1.2 Procedures and Instructions. - The supplier shall prepare or have processing, inspection and testing procedures or instructions that will be used to insure compliance with the specific requirements and controls set forth in this specification and to enable future reproducibility of the material in the same manner. These procedures shall provide for controls that will detect anomalies that will not be revealed in subsequent inspections or testing. These shall (B) include procedures and instructions for forging processes, cleaning, heat treating, ultrasonic testing, dye penetrant inspection, and etching for microstructure and macrostructure examinations. Copies of all procedures or instructions and records of conformance, including supplier's internal restricted, private and proprietary procedures representing the processes used shall be approved by an ANSC representative and retained for a period of seven (7) years. They shall be identifiable to the specific ANSC purchase order, specification and heat number.

The supplier shall submit copies of procedures and instructions to the ANSC buyer, at least ten (10) days prior to their anticipated use, for review to assure that the specific requirements of this specification are included. The procedures submitted may reference any internal restricted, private or proprietary procedures and instructions identified by the seller's control number, name and date.

ANSC directed drawing, specification and purchase order change notices shall be incorporated in previously approved procedures and instructions.

4.1.3 Reports.- Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each shipment of material traceable to lot and serial number. Any approved deviation to the requirements of this specification, applicable drawings and purchase orders shall be referenced on the applicable reports. When material is shipped which has previously been rejected by the procuring activity it shall be so indicated on the supplier shipping documents, referencing the previous rejection report. The reports shall include the following information:

(B) (a) Raw material certifications for alloying materials (aluminum and tin), specified in 3.1 and 4.3.1.

(b) Certification to specification ANS-90296.

(B) (c) Macrostructure photographs and macrograin size determinations, each bar and billet certifying compliance to 3.6.1 and 4.3.9.1.

(d) Microphotographs of acid etched areas of each bar and billet, taken at 100-200X magnification certifying compliance to 3.6.2 and 4.3.6.2.

(B) (e) Ultrasonic inspection noise levels and results for each bar and billet; the amount of cropping and types of indications (except end concavity not in excess of normal mill practice) certifying compliance to 3.9, 4.3.10, 4.3.10.1 and 4.3.10.2.

(B) (f) Liquid penetrant inspection and results for each bar and billet certifying compliance to 3.8 and 4.3.8.

(B) (g) Chemistry, representing billets identified relative to ingot location, certifying compliance to 3.2 and 4.3.2.

(h) Diagrams of billet and bar locations relative to the ingot, showing the billet location within the ingot and bar location within the billet identified from top to bottom of the ingot. The location shall be identified on the required certifications and test reports.

(B) (i) All information required in 3.10.

(B) (j) Certification that manufacturing, processing, inspection and tests were performed in accordance to procedures transmitted and on file at the seller's facility listing any revisions and deviations thereto.

(A) 4.2 Lot.- A lot shall consist of material from the same ingot of the same configuration and size and processed at the same time.

4.3 Verification.-

(A) 4.3.1 Material.- The processing procedures supplied as specified in 4.1.2 shall be reviewed to assure compliance with material requirements of 3.1.

(B) 4.3.2 Chemical Composition.- A chemical analysis made from the ends of each bar and billet shall conform to requirements specified in Table 1.

4.3.3 Heats.- The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The process controls shall provide for the inspection of anomalies that are cause for rejection of the heat.

4.3.4 Welding.- The supplier shall provide processing procedures or instructions and certify compliance with these requirements, copies of which shall be submitted to ANSC for review and approval. The procedure shall provide for the inspection of anomalies that are not acceptable.

4.3.5 Cleaning.- The suppliers process procedures or instructions shall include provisions for cleaning, to comply with 3.5.

(B) 4.3.6 Properties.-

4.3.6.1 Macrograin Size.- The supplier's procedures and instructions shall include the provisions to obtain minimum grain size in compliance with 3.6.1.

4.3.6.2 Microstructure.- Verification of equiaxed, primary alpha microstructure shall be made by metallographic preparation, examination and microphoto graphing at 100-200X at least one sample from each end of each bar and billet. Samples shall be identified as to alloy, heat number, and bar or billet number and location. Microphotographs of bar and billet microstructures, identified as to alloy, heat,and bar and billet serial numbers, shall be submitted to ANSC with copies of certifications and test reports. On the basis of the microstructure, bars and billets shall be inspected for conformance to Section 3 requirements.

Microstructure verification and microphotography using portable electropolishing and photographing methods shall be used if available. Microphotographs at 100-200X every 24 inches along each bar and billet are to be submitted; in addition, microphotographs spaced every 90° around the billet shall be made at every 48 inches along each bar and billet.

4.3.6.2.1 Finish Forging Control.- Equiaxed, primary alpha grain structure shall be obtained by finish forging billets below the beta transus temperature starting when a billet size of 16 inch diameter or square is attained.

The beta transus temperature shall be determined prior to finish forging billets to less than 16 inch diameter or square by removing a section from the 16 inch semi-finished billet sufficiently large to yield 15 0.50 inch wide, 1.00 inch long, 0.125 inch thick metallographic specimens, forged or rolled from 0.75 inch thick to 0.125 inch thick at a temperature of 1700 ± 10°F. The nominal beta transus temperature shall then be determined by heating the metallographic specimens to 1750°F, 1760°F, 1770°F (max.) etc., and in 10°F intervals, as necessary, soaking at temperature 30 minutes and then water quenching. The temperature extremes during each 30 minute soaking time interval shall be the temperatures used to determine the nominal beta transus temperature.

4.3.6.2.1.1 Beta Transus Determination.- The nominal beta transus shall be determined by metallographic examination of each of the above heat-treated samples. The nominal beta transus temperature shall be the temperature midway between the soak temperature at which some primary alpha is still evident and the temperature at which all the alpha is present in the form of transformation products such as alicular alpha. A 100-200X microphotograph of the "as-rolled" microstructure, as well as of each quenched metallographic specimen is to be submitted to ANSC prior to finish forging of billets.

4.3.6.2.1.2 Beta Transus Furnace Calibration.- Prior to beta transus determination, the furnace used for the beta transus specimen heating shall be surveyed. The temperature range within the furnace cavity to be used shall be determined using at least four independently monitored thermocouples. Furnace temperature range shall be monitored at furnace settings of 1750°F, 1800°F, and 1850°F. The furnace temperature range shall then be calculated from the greatest temperature variation observed at the three temperatures surveyed. Results of the furnace calibrations shall be submitted to ANSC prior to finish forging of billets.

4.3.6.2.1.3 Forge Shop Furnace Calibration.- The forge shop furnace temperature range may be based on the results of a past, scheduled furnace survey providing such a survey was made within 30 days prior to finish forging of the bars or billets; otherwise, special furnace surveys shall be made in accordance with normal practice in the presence of ANSC representatives. The maximum furnace temperature range shall be calculated from the greatest temperature variation observed during the survey. Nominal furnace temperature for the survey shall be 1800°F.

4.3.6.2.1.4 Finish Forging Temperature Determination.- As a result of the beta transus determination, 4.3.6.2.1, and furnace calibrations, 4.3.6.2.1.2 and 4.3.6.2.1.3, the maximum finish forging metal temperature shall be determined by reducing the nominal beta transus temperature by:

1/2 the beta transus furnace temperature range -

and further reducing by:

1/2 the maximum furnace temperature range within the furnace, or furnaces, to be used in the forge shop for finish forging the bars or billets to their finished size -

and further reducing by:

5°F, to offset heat-up from forging energy dissipation.

4.3.6.2.1.5 Finish Forging.- The maximum finish forging temperature determined in 4.3.6.2.1.4 shall not be exceeded through the remainder of the bar and billet forging process.

(A) 4.3.7 Dimensions and Tolerances.- Bars and billets shall be examined to verify conformance to dimensions and tolerances as specified in the contract or purchase order.

(B) 4.3.8 Penetrant Inspection.- Bars and billets shall be penetrant inspected in accordance with MIL-I-6866, Type I, Method A, using penetrant containing chlorine not exceeding 50 parts per million (PPM) or sulphur not in excess of 300 parts per million (PPM). Residual penetrant is to be removed by pickling or steam cleaning within 4 hours of use. Indications in excess of the acceptance criterion may be machined off and the area re-inspected providing that the bar or billet size is maintained.

(A) 4.3.9 Macrostructure and Workmanship.-

[illegible]) 4.3.9.1 Macroetch Sample Preparation and Inspection.- The top and bottom slices of each billet produced from the ingot, suitably identified by billet numbers, shall be macroetched and photographed. Each slice, so parted, shall be identified as to alloy, ingot number, and bar or billet location. Photographs of all billet macros identified to alloys and ingot numbers shall be submitted to ANSC with copies of certifications and test reports. On the basis of the macroetched surfaces, billets shall be inspected for conformance to Section 3 requirements.

(B) 4.3.10 Ultrasonic Inspection.- Bars and billets shall be lathe turned prior to ultrasonic inspection. The surface finish of lathe turned bars and billets shall be 125 RMS or better. Inspection shall be of the immersion type using both longitudinal and shear wave techniques by scanning of bars and billets while they are simultaneously turning and the carriage carrying the inspection head is traveling along their axial length. Inspection shall be performed in accordance with MIL-I-8950 except that the acceptance criteria shall be per 3.9 and the material shall be inspected for loss of back reflection as follows: When instrument is set so that the first back reflection from the correct test block is at 80 percent of the screen saturation adjusted for nonlinearity, any loss of back reflection in the material in excess of 50 percent shall be considered not acceptable.

(A) 4.3.10.1 Noise Level.- The noise level for each bar and billet shall be recorded and reported.

(A) 4.3.10.2 Calibration Standard.- The standard used for equipment calibration shall be fabricated from a bar or billet selected at random from the inspection lot. The reference notch in the calibration standard for shear wave inspection of bars, up to 4 inch diameter shall be machined to a depth of 3 to 5 percent of the full metal thickness. The reference hole in the calibration standard for longitudinal inspection of billets shall be machined to a depth of 0.150 inches. The reference hole in the calibration standard for shear wave inspection of billets shall be machined to a deptch of 0.250 inches.

(A) 4.3.10.3 Procedures.- The supplier shall provide ultrasonic testing procedures or instructions to insure compliance with these requirements which shall be submitted to ANSC for review.

(A) 4.3.10.4 Rework.- Bars or billets giving ultrasonic indications of rejectable porosity, laps, voids, enfoliation, center bursts, inclusions and detectable segregation may be used provided that areas showing these conditions have been removed, verified as to type, and end faces of removed sections have been etched and found to be free from defects. The certification or test reports for the remaining billets shall record the information relative to the rejection of any other portion.

4.3.11 Identification.- Bars and billets shall be visually inspected to verify conformance to Section 3 requirements. .

Section 5. PREPARATION FOR DELIVERY

5.1 Packaging.- Each product shall be packaged to prevent damage during handling and shipping.

(A) 5.2 Marking.- Containers shall be marked in accordance with Standard MIL-STD-129. Marking shall include the following information:

(a) Manufacturers name
(b) Material identification
(c) Lot number and heat number
(d) Bar or billet serial number(s)
(e) Purchase order number.

Section 6. NOTES

6.1 Intended Use.- Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components, requiring high reliability and operating in the temperature range of +90°F to -423°F.

6.2 Ordering Data.- Procurement documents should specify the following information:

(a) This specification number
(b) Size and shape, as required
(c) Quality Control Standard Clauses
    (1) Source surveillance
    (2) Source acceptance
    (3) Source Inspection-Government

TABLE II

VERIFICATION CROSS REFERENCE INDEX

	Section 3 Requirement Paragraph	Verification													Section 4 Verification Method Paragraph
		Method													
		Not Applicable	Inspection	Analysis	Demonstration	Test									
(A)	3.1		X	X											4.3.1
	3.2			X		X									4.3.2
	3.3		X												4.3.3
	3.3.1	X													
(A)	3.3.1.1		X	X											4.3.3
(A)	3.3.1.2		X	X											4.3.3
(A)	3.3.1.3		X	X											4.3.3
	3.3.2	X													
(A)	3.3.2.1		X	X											4.3.3
(A)	3.3.2.2		X	X											4.3.3
(A)	3.3.2.3		X	X											4.3.3
	3.4	X													
(A)	3.4.1		X	X											4.3.4
(A)	3.4.2		X	X											4.3.4
	3.5		X												4.3.5
	3.6		X												4.3.6
(A)	3.6.1					X									4.3.6.1
(B)	3.6.2					X									4.3.6.2
(A)	3.7		X	X											4.3.7
(A)	3.8			X		X									4.3.8
(A)	3.9			X		X									4.3.10
(A)	3.10		X												4.3.11

N8300R:72-103
May 1972

ENCLOSURE 3

SPECIFICATION ANS-90297D,
TITANIUM ALLOY 5Al-2.5 Sn ELI, BARS AND FORGINGS

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET - GENERAL

POST OFFICE BOX 13070 • SACRAMENTO, CALIFORNIA 95813
CODE IDENT 34632

SPECIFICATION ANS-90297D

TITANIUM ALLOY, 5AL-2.5SN ELI, BARS AND FORGINGS

SUPERSEDING:		
AGC- ANS-90297 DATE 12-28-70	AGC- DATE	AGC- DATE

RELEASES (REPLACE PAGES IN SPECIFICATION WITH LATEST CHANGE BELOW)

REV LTR	RELEASE DATE	PAGE NUMBERS																PAGE ADDITIONS
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	12-28-70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
A	1-21-71	A					A					A	A			A	A	
B	6-28-71						B											
C	12-16-71			C	C	C	C	C		C	C	C	C	C				
D	1-19-72								D						D			

Authorized for release:

12-16-71

ANSC Specifications and Standards

ANSC 62-1C (10/70)

Section 1. SCOPE

1.1 Scope.- This specification establishes the requirements for Extra Low Interstitial (ELI) titanium alloy (5Al-2.5Sn) bars and forgings.

1.2 Classification.- This product shall be classified as follows:

Suffix No.	Designation
-1	Bars (See 3.3.1)
-2	Pancake Forgings (see 3.3.2)
-3	Die Forgings (see 3.3.3)

Each classification shall be called out by referencing the specification number, plus the suffix number designating the classification desired.

Section 2. APPLICABLE DOCUMENTS

2.1 Department of Defense Documents.- Unless otherwise specified, the following documents, listed in the issue of the Department of Defense Index of Specifications and Standards in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-I-6866	Inspection, Penetrant, Method of
MIL-H-81200	Heat Treatment of Titanium and Titanium Alloys
MIL-I-8950	Inspection, Ultrasonic, Wrought Metals, Process for

STANDARDS

Federal

FED-STD-151	Metals; Test Methods
FED-STD-184	Identification Marking of Aluminum, Magnesium, and Titanium

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-453	Inspection, Radiographic

(Copies of documents required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards.)

2.2 Other Documents.- Unless otherwise specified, the following documents of the issue in effect on date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

Society of Automotive Engineers

(C)	AMS 2241	Tolerances - Corrosion and Heat Resistant Steel Bars and Wire and Titanium and Titanium Alloy Bars and Wire

(Copies of Aeronautical Materials Specifications may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York 17, N.Y.)

PUBLICATION

American Society for Testing and Materials

	ASTM E8	Tension Testing of Metallic Materials
(C)	ASTM E112	Estimating the Average Grain Size of Metals

(Copies may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia 3, Pennsylvania).

2.3 Aerojet Nuclear Systems Company Documents.- Unless otherwise specified, the following documents of the latest issue in effect, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

ANS-90295	Titanium Alloy, 5Al-2.5Sn ELI, Bars and Billets
ANS-90296	Titanium Sponge
ANS-9032	Quality Standards for Wrought and Forged Products

Section 3. REQUIREMENTS

3.1 Material.- The material used for producing bars and forgings shall comply with the requirements specified in ANS-90295 and 90296.

3.2 Chemical Composition.- The chemical composition shall be in accordance with Table I.

TABLE I

	Element	Percent Min.	Percent Max.
	Aluminum	4.70	5.60
	Tin	2.00	3.00
	Manganese		0.03
	Iron		0.25
(C)	Oxygen		0.10
	Carbon		0.05
(C)	Nitrogen		0.02
	Hydrogen		0.0100
	Other elements, each 1/		0.05
	Other elements, total 1/		0.20
	Titanium	Remainder	

1/ Need not be reported

3.3 Condition.-

3.3.1 Bars (ANS-90297-1).- Bars shall be supplied in the hot finished condition, with or without subsequent cold reduction, annealed (see 3.5) and descaled.

3.3.2 Pancake Forgings (ANS-90297-2).- Forgings shall be supplied rough machined to eliminate contaminated surface skin, followed by vacuum annealing (see 3.5).

3.3.3 Die Forgings (ANS-90297-3).- Forgings shall have contaminated skin removed, consistent with forging dimensional requirements. Forgings shall be vacuum annealed (see 3.5)

3.4 Forging Process.- The material shall be forged by hammering, pressing, rolling, extruding or upsetting. It shall be brought as nearly as practicable to the finished shape and size by hot-working and shall be so processed as to cause uniform metal flow in all directions during the hot-working operation. If three or more forgings are to be made from one billet or if the available billets or bars exceed 30 inches in length, additional macrostructure examinations and macrophotographs shall be made at the cut billet ends in accordance with the requirements specified in ANS-90295.

3.5 Heat Treatment.- Unless otherwise specified, all material supplied to this specification shall be vacuum annealed by heating to 1400^{O}F $\pm$ 25^{O}F at a pressure of 0.1 micron or less and holding at temperature in vacuum for 1 hour per inch of thickness in maximum direction, but no less than 2 hours.
(C) Cooling from the annealing temperature to 1000^{O}F shall be accomplished in a period of 10 minutes or less either in vacuum or by using helium purging. Further cooling to 300^{O}F shall also be carried out in vacuum or with helium but without time restrictions. Final cooling to room temperature may be in air. Heat treating equipment and the applicable heat treating requirements shall conform to the requirements as specified in MIL-H-81200.

3.6 Surface Quality.- The material shall be free of oxide scale and contaminated skin. The surfaces to be penetrant inspected shall not be subjected to particle impact cleaning. The acceptance level shall conform to ANS-9032-1.

3.7 Internal Condition.-

(A) 3.7.1 Internal Quality.- Internal conditions shall conform to the following. Repair of defects by welding shall not be permitted.

(A) 3.7.1.1 Forgings.- Forging internal quality shall conform to Class AAA, of MIL-I-8950. Pancake and die forgings shall be radiographically inspected and the quality level shall conform to ANS-9032-1.

(C) 3.7.1.2 Bars.- Bar internal quality shall be ultrasonically inspected and the quality level shall conform to MIL-I-8950AAA.

3.7.2 Microstructure.- When examined microscopically after suitable etching, the structure of the finished product shall be approximately equiaxed, primary alpha with no evidence of titanium hydrides. There shall be no evidence of transformation products such as acicular alpha, a continuous alpha network surrounding large prior beta grains, or large prior beta grains. The microstructure shall indicate that the material has been finish forged or
(C) rolled at a temperature below the beta transformation temperature and that no subsequent thermal treatment above the beta transformation temperature has been applied. Beta constituents, if present, shall be fine, randomly distributed, and shall not exceed 5 percent of any cross sectioned area. For cross sectional thicknesses under 2.0 inches, grain size shall be 8 or finer, for sections over 2.0 inch and under 6.0 inch, grain size shall be 5 or finer. Grain size for sections over 6.0 inches shall be as agreed upon by the procuring activity and the supplier. Method of verifying grain size shall be in accordance with ASTM E112.

3.7.3 Macrostructure.-

3.7.3.1 Pancake Forgings.- Macrostructure examination shall show no predominant grain flow in any one direction and no evidence of alloy segregation. Grains of similar size shall be distributed at random and not oriented in bands.

3.7.3.2 Die Forgings.- Macrostructure examination shall reveal grain flow predominantly parallel to the forging shape and no evidence of alloy segregation. Die mismatch shall be held to a maximum of 0.06 inch.

3.7.3.3 Bar.- Macrostructure examination shall reveal longitudinal grain flow along the length of the bar with no evidence of alloy segregation.

3.8 Room Temperature Tensile Properties.- Room temperature tensile properties from material forged as specified in 3.4 and annealed as specified in 3.5 shall be as follows:

(a)	Tensile strength, psi, min.	110,000
(b)	Yield strength, 0.2% offset, psi, min.	100,000
(c)	Elongation, % in 1 in. or 4D, min.	12
(d)	Reduction in area, %, min.	25

3.9 Dimensions and Tolerances.- Except as otherwise specified, tolerances for bars shall conform to the requirements specified in AMS 2241. Tolerances for forgings shall be as specified on the applicable drawing.

3.10 Identification.- Each bar shall be marked in accordance with FED-STD-184. The marking information shall include this specification and suffix number, heat number, serial number, and the manufacturers name or trademark. Forgings shall be marked in accordance with the requirements specified on the applicable drawing.

3.11 First Piece Inspection.- A first piece inspection shall be per-
(D) formed to insure the production lot will meet all requirements of this specification.

Section 4. QUALITY ASSURANCE PROVISIONS

4.1 Suppliers Responsibility.-

4.11 Inspection.- Unless otherwise specified, the supplier is responsible for the performance of all inspection specified herein. Special processes and nondestructive testing shall be performed by Aerojet Nuclear Systems Company (ANSC) approved sources. The method of verification shall be in accordance with Table II.

4.1.2 Procedures and Instructions. - The supplier shall prepare or have processing, inspection and testing procedures or instructions that will be used to insure compliance with the specific requirements and controls set forth in this specification and to assure future reproducibility of the material in the same manner. These procedures shall provide for controls that will detect anomalies that will not be revealed in subsequent inspections or testing. These shall (C) include procedures and instructions for forging processes, cleaning, heat treating, ultrasonic testing, dye penetrant inspection, and etching for microstructure and macrostructure examinations. Copies of all procedures or instructions and records of conformance, including supplier's internal restricted, private and proprietary procedures representing the processes used shall be approved by an ANSC representative and retained for a period of seven (7) years. They shall be identifiable to the specific ANSC purchase order, specification and heat number.

The supplier shall submit copies of procedures and instructions to the ANSC buyer, at least ten (10) days prior to their anticipated use, for review to assure that the specific requirements of this specification are included. The procedures submitted may reference any internal restricted, private or proprietary procedures and instructions identified by the seller's control number, name and date.

ANSC directed drawing, specification and purchase order change notices shall be incorporated in previously approved procedures and instructions.

4.1.3 Reports. - Unless otherwise specified, the supplier of the product shall furnish with each shipment three copies of a report giving, where applicable, the actual values obtained as a result of tests verifying conformance to the requirements of this specification. Separate reports shall be submitted for each shipment of material traceable to lot and serial number. Any approved (C) deviation to the requirements of this specification, applicable drawings and purchase orders shall be referenced on the applicable reports. When material is shipped which has previously been rejected by the procuring activity it shall be so indicated on the supplier shipping documents, referencing the previous rejection report. The reports shall include the following information, with certifications for each of the following requirements:

(a) Certifications for material specified in 4.3.1.
(b) Chemical test reports specified in 3.2 and 4.3.2.

(c) Detailed log of forging history specified in 4.3.4 and certification of compliance to approved procedures and instructions.

(d) Certification of compliance to heat treatment requirements specified in 3.5 and 4.3.5 and approved procedures and instructions.

(e) Certification of conformance to surface quality specified in 3.6 and 4.3.6.

(C) (f) Ultrasonic test report shall include continuous facsimile type recording (e.g. C-Scan) produced by synchronous motion of transducer,test article and recording paper with certification of compliance to 3.7.1 and 4.3.7.1.1.

(C) (g) Liquid penetrant inspection and results for each forging certifying compliance to 3.6 and 4.3.6.2.

(C) (h) Radiographic film and test reports certifying compliance to 3.7.1 and 4.3.7.1.2.

(i) Microphotographs certifying compliance to 3.7.2 and 4.3.7.2.

(C) (j) Macrophotographs certifying compliance to 3.7.3 and 4.3.7.3.

(C) (k) Tensile test reports specified in 3.8 and 4.3.8.

4.2 Lot. - A lot shall consist of bars or forgings from the same billet lot, rolled or forged at the same temperature, be of the same configuration and size (forged from identical dies, if die forgings), and heat treated in the same heat treatment run.

4.3 Verification. -

4.3.1 Material. - For material purchased, the supplier shall provide traceable copies of the manufacturers reports evidencing compliance with the requirements of ANS-90295 and 90296. When material is furnished by ANSC the supplier shall certify to the use of the ANSC supplied material. The identification of the furnished material shall be maintained and be traceable to the identification of the finished bars and forgings and the related reports specified herein.

4.3.2 Chemical Composition.- A chemical analysis shall be made on a test sample from a bar or forging from each billet lot. In addition, two analyses for hydrogen shall be made. One sample shall be obtained at or near the surface of each bar or forging, and a second sample shall be obtained near the center
(C) of the sectioned bar or forging specified in 4.3.7.3. Samples shall be obtained after all processing is complete. The chemical analysis shall conform to requirements specified in Table I.

4.3.3 Condition.- Examine visually.

4.3.4 Forging Process.- The supplier shall maintain a detailed log of the forging history (thermal and mechanical work) for each forging evidencing compliance with the requirements specified in 3.4.

4.3.5 Heat Treatment.- The supplier shall maintain a control on heat treatment that shall provide a positive record of heat treatment evidencing compliance with the requirements specified in 3.5.

4.3.6 Surface Quality.-

4.3.6.1 Visual.- Examine for absence of oxide scale, contaminated skin and imperfections.

(C) 4.3.6.2 Penetrant Inspection.- Penetrant inspection shall be in accordance with MIL-I-6866, Type I, Method A, using penetrant containing chlorine not exceeding 50 parts per million (PPM) or sulphur not in excess of 300 PPM. Residual penetrant is to be removed by steam cleaning within 4 hours of use.

4.3.6.3 Rework.- Rejectable surface imperfections may be removed within the dimensional tolerance limits specified on the drawing, followed by reinspection of the reworked area for surface quality.

4.3.7 Internal Condition. -

4.3.7.1 Internal Quality. -

(C) 4.3.7.1.1 Ultrasonic Inspection. - Ultrasonic inspection shall be in accordance with MIL-I-8950. Forging and bar inspection shall use both longitudinal and shear wave techniques. The surface finish of bars or forgings to be inspected shall be 125 RMS or better. Inspection shall be of the immersion type. The ultrasonic standard used for forgings shall be fabricated from a forging of the same alloy, of similar configuration as the forging being inspected. The instrument shall be adjusted to compensate for response differences between the reference standard and the part being inspected. The reference holes for longitudinal inspection shall be of 1/64, 3/64 and 5/64 inch diameters machined to 0.150 inch depth in the thickest half section. The reference holes for shear wave inspection shall be of the same diameters machined at a 45 degree angle to 0.250 inch depth. The standard for shear wave inspection of bars shall be a notch of 3 to 5 percent of the bar thickness not exceeding 0.025 inch.

4.3.7.1.2 Radiographic Inspection. - Radiographic inspection shall be performed in accordance with MIL-STD-453. All discontinuities observed that approach or exceed the acceptance criteria shall be reported and identified as to location and size.

4.3.7.2 Microstructure. -

4.3.7.2.1 Bars. - One bar from each lot shall be selected for microstructure examination. Verification shall be determined by suitably etching and examining the threaded end of a tensile specimen after it has been tested. The microstructure shall be examined and photographed to determine conformance to 3.7.2.

(C) 4.3.7.2.2 Forgings.- The microstructure of each forging shall be examined. Verification shall be determined by suitably etching and examining the threaded end of one radial and one tangential tensile specimen after such specimens have been tested. Photographs of the microstructures examined and photographed at 100-200X to determine conformance to 3.7.2 shall be identified as to alloy, part number, and serial number and submitted to ANSC.

4.3.7.3 Macrostructure.-

4.3.7.3.1 Pancake Forgings.- One forging of each configuration of each lot shall be sectioned and tested for determination of macrostructure. At least half of each section of the forging shall be furnished to the procuring activity for review and verification tests. The macrostructure shall be photographed and examined for conformance to 3.7.3.1.

4.3.7.3.2 Die Forging.- Same as 4.3.7.3.1 except conformance shall be to 3.7.3.2.

4.3.7.3.3 Bars.- A 12 inch sample shall be cut from the end of one bar from each lot, sectioned longitudinally, suitably etched, examined and photographed to determine conformance to 3.7.3.3.

4.3.8 Room Temperature Tensile Properties.-

4.3.8.1 Bars.- Two 0.250 inch diameter round tensile specimens shall be machined from each lot of bars in accordance with ASTM-E8 to determine room temperature tensile properties.

4.3.8.2 Forgings.- The number of tensile test specimens and the location and direction on the forging(s) from which the test specimens are obtained shall be as specified on the drawing.

4.3.8.3 Test Method.- Bars and forgings tensile test specimens obtained as specified in 4.3.8.1 and 4.3.8.2 shall be tested in accordance with ASTM-E8 using a strain rate of 0.005 $\pm$ .002 inch per inch per minute through the yield strength and then increased so as to produce failure in approximately one additional minute. Tensile properties shall apply in all directions.

4.3.8.4 Retesting.- Retesting for mechanical properties shall be allowed under the following conditions:

(a) The provisions for retesting are in accordance with FED-STD-151 or a procedure proposed by the supplier and approved by the procuring activity.

(b) The specimens are taken from a location adjacent to the specimen failing the original test.

(c) Test results for all specimens, including those failing to meet the requirements, are reported to the procuring activity.

4.3.9 Dimensions and Tolerances.- Bars and forgings shall be examined to verify conformance to dimensions and tolerances as specified.

4.3.10 Identification.- Bars and forgings shall be examined visually for conformance to Section 3 requirements.

4.3.11 First Piece Inspection.- A first piece inspection shall be performed on a sample forging for each configuration produced prior to production (D) runs, using the same equipment, tooling and methods to be used for the production lot. This first piece inspection shall be repeated whenever there is a change in forging configuration, equipment, tooling, methods and billet heat. Inspections shall be performed to verify all the requirements specified herein.

Section 5. PREPARATION FOR DELIVERY

5.1 Packaging.- Each product shall be packaged in such a manner so as to prevent damage during handling and shipping.

5.2 Marking.- Containers shall be marked in accordance with MIL-STD-129. Marking shall include the following information:

(a) Forgings Part Number
(b) Bars- the number of this specification and applicable suffix number and size (see 1.2)
(c) The lot, heat and serial numbers
(d) Manufacturers name
(e) The purchase order number

Section 6. NOTES

6.1 Intended Use.- Material produced to this specification is intended for use in critical, cryogenic rocket vehicle components requiring high reliability and operating in the temperature range of +90°F to -423°F.

(A) 6.2 Ordering Data.- Procurement documents should specify the following information:

(a) This specification number and applicable suffix number (see 1.2)
(b) Size and shape, as required
(c) Quality Control Standard Clauses
    (1) Source surveillance
    (2) Source acceptance
    (3) Source inspection-Government

TABLE II

VERIFICATION CROSS REFERENCE INDEX

	Section 3 Requirement Paragraph	Verification										Section 4 Verification Method Paragraph
		Method										
		Not Applicable	Inspection	Analysis	Demonstration	Test						
	3.1		X									4.3.1
(C)	3.2			X		X						4.3.2
	3.3	X										
	3.3.1		X									4.3.3
	3.3.2		X									4.3.3
	3.3.3		X									4.3.3.
	3.4		X									4.3.4
(B)(C)	3.5		X									4.3.5
	3.6		X									4.3.6
	3.7	X										
(A)	3.7.1		X									
(A)	3.7.1.1		X									4.3.7.1.1
(A)(C)	3.7.1.2		X									4.3.7.1.2
(C)	3.7.2		X									4.3.7.2
	3.7.3	X										
	3.7.3.1		X									4.3.7.3.1
	3.7.3.2		X									4.3.7.3.2
	3.7.3.3		X									4.3.7.3.3
	3.8			X		X						4.3.8
	3.9		X									4.3.9
	3.10		X									4.3.10
(D)	3.11		X									4.3.11

AEROJET NUCLEAR SYSTEMS COMPANY
A DIVISION OF AEROJET-GENERAL

DOCUMENT APPROVAL SIGNATURE SHEET

TYPE OF DOCUMENT		DOCUMENT NO.
MATERIAL SPECIFICATION		ANS-90297D

TITLE

TITANIUM ALLOY, 5AL-2.5SN ELI, BARS AND FORGINGS

PREPARED BY	ORGANIZATION	EXTENSION
P. P. Dessau	N8130	6568

APPROVAL SIGNATURE	ORGANIZATION	DATE
F. E. Porter, Manager Quality Engineering Section by J. M. Amend	N7000	1-19-72
N. A. Edlebeck, Manager Turbopump Department N. Edlebeck	N8300	1-19-72
T. A. Redfield, Manager Materials Section T. A. Redfield	N8130	1/14/72

ANSC 81, 2C (12/70)

N8300R:72-103
May 1972

ENCLOSURE 4

SUPPLIERS INFORMATION REQUEST NO. 13273

AEROJET GENERAL ®

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

SUPPLIERS INFORMATION REQUEST

№ 13273

0614-12

PAGE OF

DATE	NEXT ASSEMBLY	PART NAME	PART NO.	SERIAL NO.
3-2-71		Billet 8" Diameter		XI thru X

REQUESTED BY (SUPPLIERS NAME) Initiated by ANSC	AFFECTED ORDER	AFFECTED SERIAL NO'S.	QUANTITY AFFECTED	QUANTITY ORDERED
Titanium Metals Corporation of America 722 Sycamore Street Los Angeles, Calif. 90040	Req. No. N-01331	XI thru X	5,000 lb. Ingot	Same

THE FOLLOWING CONDITION AFFECTS THE PARTS DESCRIBED HEREON. THE SUPPLIER ACCEPTS FULL RESPONSIBILITY FOR THE CORRECTNESS OF THE INFORMATION SUBMITTED.

PROBLEM:

Forging supplier recommends that micro structures of billets supplied to them shall show no evidence of heating over the Beta transus.

RECOMMENDED SOLUTION:

Modify purchase order by copy of this SIR that micro structures ~~taken~~ taken of billet per ANS-90295A shall show no evidence of heating over the Beta transus.

ADDITIONAL UNIT COST	REDUCED UNIT COST	REQUESTED BY (INDIVIDUAL)	TITLE
$	$	[signature] 3/2/71	Materials Engineer/ANSC

FOR AEROJET-GENERAL CORPORATION USE ONLY

DISPOSITION: Concur with above recommended Solution
C. R. Harris 3-2-71

REVIEWED BY		
	RESIDENT ENGINEER	REQUISITIONER
	BUYER R. R. Gale 3/2/71	QUALITY ENGINEERING R. J. Diko 3/2/71
	PROJECT ENGINEER C. L. Harris 3-2-71	OTHER
FINAL APPROVAL OF DISPOSITION	NAME	TITLE

DISTRIBUTION

✓	TO	NO COPIES	✓	TO	NO COPIES
	RESIDENT ENGR		✓	VENDOR	6
✓	BUYER	1	✓	Q. E.	2
✓	REQUISITIONER	2		OTHER	
✓	PROJ				

345

N8300R:72-103
May 1972

ENCLOSURE 5

SUPPLIERS INFORMATION REQUEST, NO. 13270

SUPPLIERS INFORMATION REQUEST

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

№ 13270

AGC 0614-12

PAGE 1 OF 1

DATE	NEXT ASSEMBLY	PART NAME	PART NO.	SERIAL NO.
2-24-71		Billet 8" Diameter		XI thru X

REQUESTED BY (SUPPLIER'S NAME) Initiated by ANSC	AFFECTED ORDER	AFFECTED SERIAL NO'S.	QUANTITY AFFECTED	QUANTITY ORDERED
Titanium Metals Corporation of America 7225 Sycamore Street Los Angeles, Calif. 90040	Req. No. N-01331	XI thru X	5,000 lb. Ingot	Same

THE FOLLOWING CONDITION AFFECTS THE PARTS DESCRIBED HEREON. THE SUPPLIER ACCEPTS FULL RESPONSIBILITY FOR THE CORRECTNESS OF THE INFORMATION SUBMITTED.

PROBLEM:
1. ANS - 90296A, Para. 3.2 specifies density of Sponge 35 to 40 lbs. per cubic foot. Supplier quotes "Bulk density shall be 66-76# 1 cu. ft."
2. ANS-90296A, Para. 4.3 dpecifies sampling method A and Method B, and Para. 4.4.4 specifies chemical analysis shall be in accordance with ASTM-E-120 or ANSC approved alternate method. Supplier quotes - "Our methods will have to be approved by ANSC."
3. ANS - 90295A, Para. 3.3.1.1 Vacuum level shall not exceed 1000 Microns. Supplier quotes. - "Vacuum level shall not exceed 6000 Microns."
4. ANS - 90295A, Para. 3.4.1 specifies welding shall be performed using methods that preclude contamination such as, Tungsten, inclusions, slag and oxides. Supplier quotes "A controlled amount of oxide contamination is inherent in our welding procedures.

RECOMMENDED SOLUTION:
1. Approve supplier's quote.provided domestic sponges used.
2. Supplier's sampling and chemical analysis methods approved. Supplier to submit copies to ANSC for information and review.
3. Approve supplier's quote.
4. Post weld oxide discloration shall be removed entirely by wire brushing and compliance shall be verified by ANSC representative.

ADDITIONAL UNIT COST	REDUCED UNIT COST	REQUESTED BY (INDIVIDUAL)	TITLE
$	$	[signature] 2/24/71	Materials Engineer/ANSC

FOR AEROJET-GENERAL CORPORATION USE ONLY

DISPOSITION:

Approved recommended solutions noted above. C. L. Harris Feb. 24, 1971

REVIEWED BY		
	RESIDENT ENGINEER	REQUISITIONER
	BUYER [signature] 2/24/71	QUALITY ENGINEERING
	PROJECT ENGINEER C. L. Harris 2/24/71	OTHER [signature] 2-24-71
FINAL APPROVAL OF DISPOSITION	NAME	TITLE

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	RESIDENT ENGR		✓	VENDOR	6
✓	BUYER	1	✓	Q. E.	1
✓	REQUISITIONER	1		OTHER	
✓	PROJ ENGR	1		OTHER	

N8300R:72-103
May 1972

ENCLOSURE 6

INFORMATION RELATIVE TO TMCA,HEAT K8930, TI 5Al-2.5 Sn ELI

ENCLOSURE 6

INFORMATION RELATIVE TO TMCA
HEAT K 8930, Ti 5Al-2.5Sn ELI

ANSC P. O. N01331

Material Specs.	ANS 90295 and 90296	
Sponge/Batch Nos.	5617	2213 pounds
	5695	2132 pounds
	5643	2106 pounds
	5727	2190 pounds
TOTAL		8641 pounds

Sponge blends (made up from above four batches):

21417 D/A	4200 pounds
21417 D/B	4400 pounds

Batches were double blended into the two blends, A and B

Bulk Density: 71.6 lb/ft^3

N8300R:72-103
May 1972

ENCLOSURE 7

SEQUENCE OF ANSC INGOT REDUCTION,
TMCA HEAT K8930

ENCLOSURE 7

SEQUENCE OF ANSC INGOT REDUCTION
TMCA HEAT K8930

	OPERATION OPERATION	CONDITIONING TEMP. °F	COMMENTS
1.	Axial Upset	2200	Extra step used to insure fine macrograin.
2.	Reheat	2200	-
3.	Forge to 24" Square	-	Five passes under heavy press.
4.	Reheat	2200	-
5.	Forge to 16" Square	-	Largest reduction; evidence of work at bar centerline by scale flashing off; only cracking noted was at bottom end of bar.
6.	Bar Hot Cut	-	Cut made 40% from bottom while bar still hot.
7.	Reheat	2200	Bar portions controlled such that bottom placed in furnace first with bottom facing furnace wall; larger piece placed next to small piece with top facing furnace door. No other material in furnace.
8.	Forge to 12" RCS - both pieces		-
9.	Water quench - both pieces		Extra step used to achieve fine alpha grain precipitation.
10.	Grind bars all over	-	Was expedited due to ANSC observer at mill.
11.	Heat-Up	1840	-
12.	Bars Hot Cut	-	B Bar cut into 2 pieces B and T4; top bar cut in 3 pieces, T3, T2, and T. Bar identification was closely watched and controlled.
13.	Forge to 9-1/2 square	-	Extra step to prevent cracking; normally material is forged directly to 8-1/2 inch. Small cracks noted on T3.
14.	Reheat	1840	-
15.	Forge to 8-1/2 Square	-	Bars Elongated to 110 - 120 inches, each. Small cracks noted in T3 and T4.
16.	Reheat	1840	-
17.	Forge to 8-1/2 Round	-	-

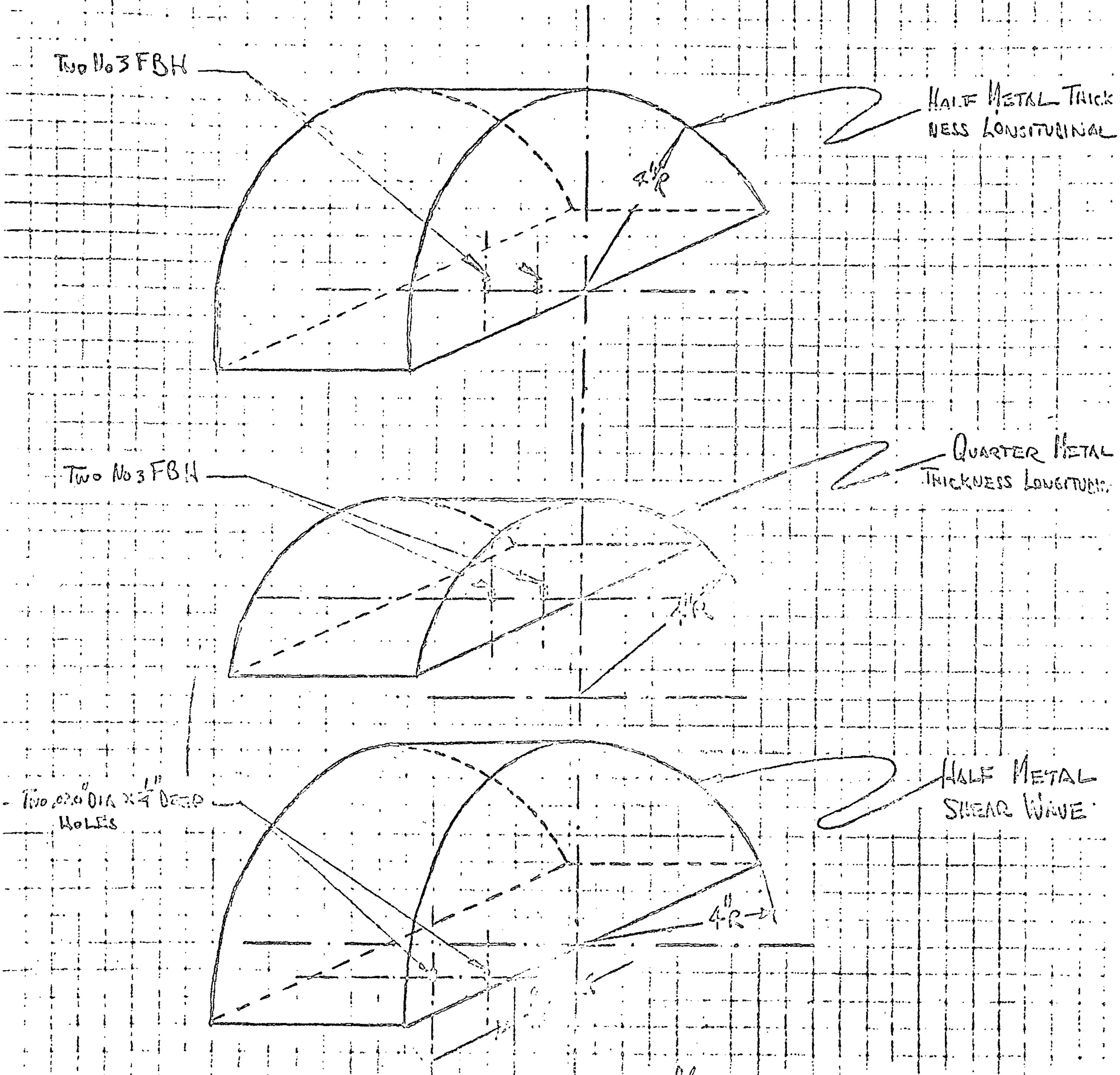
N8300R:72-103
May 1972

ENCLOSURE 8

ULTRASONIC STANDARDS

ENCLOSURE 8

ULTRASONIC STANDARDS



MATERIAL FROM BOTTOM END OF ?" COLLET.

ENCLOSURE 9

TMCA CERTIFICATION OF TEST, NOTICE OF SHIPMENT

Titanium Metals Corporation of America

TMCA 1260

First in Titanium

195 CLINTON ROAD WEST CALDWELL, NEW JERSEY 07006

SALES ORDER

CERTIFICATE OF TEST

NOTICE OF SHIPMENT

INVOICE NUMBER	DATE
757565	Aug 5, 1971

VIA	GROSS	TARE	NET
Lee Way	1748	20	1728

ITEM	DESCRIPTION			NO. PCS.	SQUARE FEET	WEIGHT
1	8"DIA x 10-12 Ft RL					
	Heat K-8930	48-1/8"	Bar T	1		389
		48"	T1	1		388
		116-5/8"	T2	1		951
	58-56902 (01-3)					

Titanium Metals Corporation of America

CERTIFICATE OF TEST

CHEMICAL ANALYSIS

HEAT NO.	C	FE	N	AL	VA	CR	MO	H	ZR	SN	MN	O2
[illegible]3030 T	.020	.183	.009	5.04				.007		2.43	.008	.072
T2U	.014	.180	.009	5.02				.008		2.42	.008	.080
T2	.016	.180	.012	4.97				.008		2.43	.008	.072
T2U	.020	.150	.010	5.07				.008		2.42	.007	.084

MECHANICAL PROPERTIES

HEAT NO.	TEST NO.	SIZE OR GAUGE	YIELD STRENGTH	TENSILE STRENGTH	ELONG.	R. A. %	HARDNESS	BEND TEST
		8"DIA	P.W. 2 to 3/4" @ 1850°F					
			Ann 1 hr @ 1300°F AC				RC	
T-3030			114,200	125,000	[illegible]	[illegible]	35.5	
			116,200	122,000	[illegible]	[illegible]	35.5	
			100,300	120,300	[illegible]	[illegible]	[illegible]	
			112,300	122,200	[illegible]	[illegible]	[illegible]	

Scale OK, Ultrasonic [illegible]
Sponge produced in accordance with [illegible]
Macrostructure and [illegible] OK

Subscribed And Sworn To Before Me

This Date 9-5-73

356

Results As Above Certified
Titanium Metals Corporation of America

[signature]

TMCA 1500

Titanium Metals Corporation of America

First in Titanium

195 CLINTON ROAD WEST CALDWELL, NEW JERSEY 07006

SALES ORDER

SOLD TO

SHIP TO

CERTIFICATE OF TEST

NOTICE OF SHIPMENT

	INVOICE NUMBER	DATE
	757566	Aug 5, 1971

VIA	GROSS	TARE	NET
Tmco Truck & United Air Frt	1831	72	1759

	DESCRIPTION	NO. PCS.	SQUARE FEET	FILLING WT. PER PIECE OR SQ. FT.	WEIGHT
1	8"DIA x 10-12 Ft RL				
	Heat K-8930 109-5/8" Bar T4	1			893
	107" B	1			866

RECEIVED
AUG 11 1971
ARCTURUS MFG. CO.

58-56902 (01-2)

[illegible] Corporation of America

CERTIFICATE OF TEST

CHEMICAL ANALYSIS

HEAT NO.	C	FE	N	AL	VA	CR	MO	H	ZR	SN	MN	O2
K-8930	TA .020	.140	.010	5.00				.003		2.49	.003	.002
	TM .018	.130	.013	4.92				.002		2.40	.003	.087
	B .022	.125	.012	4.87				.003		2.42	.003	.074
	BM .022	.125	.010	5.13				.003		2.44	.003	.099

MECHANICAL PROPERTIES

HEAT NO.	TEST NO.	SIZE OR GAUGE	YIELD STRENGTH	TENSILE STRENGTH	ELONG.	R. A. %	HARDNESS	BEND TEST
		3" Dia	F.S. 2 to 3/4" @ 1850°F					
			Ann 1 Hr @ 1300°F AC				RC	
K-8930			114,300	125,900	14.0	[illegible]	26.5	
			116,300	122,300	14.0	[illegible]	25.5	
			109,300	120,300	13.0	[illegible]	25.0	
			112,300	121,100	13.0	[illegible]	25.0	

Sonic OK, Immersion [illegible]
Sponge produced in accordance with [illegible] 9029A
Macrostructure and macro grain size OK

Subscribed And Sworn To Before Me
9-5-73

358

Results As Above Certified
Titanium Metals Corporation of America
[illegible signature]

N8300R:72-103
May 1972

ENCLOSURE 10

SUPPLIERS INFORMATION REQUEST, NO. 13276

ENCLOSURE

SUPPLIERS INFORMATION REQUEST

AEROJET-GENERAL CORPORATION SACRAMENTO · CALIFORNIA

№ 13270

0614-12

PAGE OF

DATE	NEXT ASSEMBLY	PART NAME	PART NO.	SERIAL NO.
3-8-71		8" dia. Billet		X21 thru X2

REQUESTED BY (SUPPLIERS NAME) Initiated by ANSC	AFFECTED ORDER	AFFECTED SERIAL NO'S.	QUANTITY AFFECTED	QUANTITY ORDERED
Reactive Metals, Inc. Niles, Ohio 44446	Req #N-01365	X21 thru X2	5,000 lb. Ingot	Same

THE FOLLOWING CONDITION AFFECTS THE PARTS DESCRIBED HEREON. THE SUPPLIER ACCEPTS FULL RESPONSIBILITY FOR THE CORRECTNESS OF THE INFORMATION SUBMITTED.

PROBLEM:

Forging supplier recommends that micro structures of billets supplied to them shall show no evidence of heating over the beta transus.

RECOMMENDED SOLUTION:

Modify purchase order by copy of this SIR that micro structures taken from billet per ANS-90295A shall show no evidence of heating over beta transus.

ADDITIONAL UNIT COST	REDUCED UNIT COST	REQUESTED BY (INDIVIDUAL)	TITLE
$	$	3/8/71	Materials Engineer/ANSC

FOR AEROJET-GENERAL CORPORATION USE ONLY

DISPOSITION: Concur with above recommended solution
C. L. Harris 3/8/71

REVIEWED BY

RESIDENT ENGINEER

BUYER 3/8/71

PROJECT ENGINEER 3/8/71

FINAL APPROVAL OF DISPOSITION

NAME

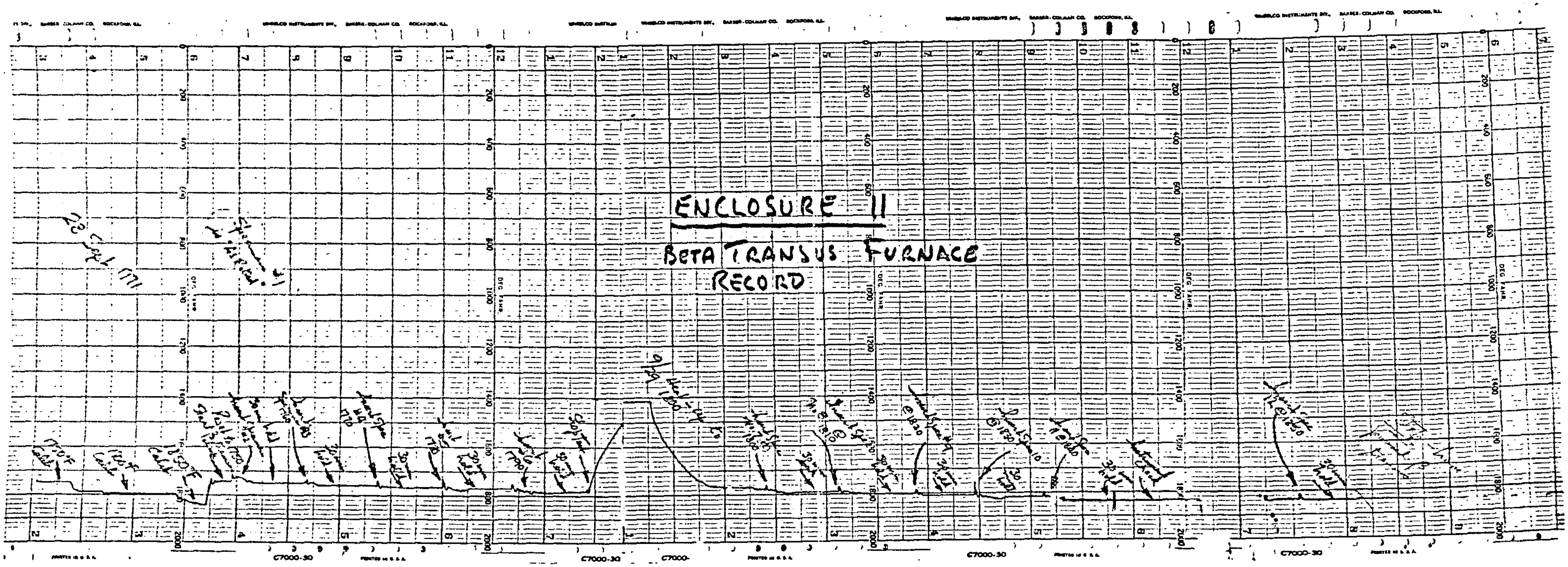
TO: RESIDENT, BUYER, PROJ ENGR

360

N8300R:72-103
May 1972

ENCLOSURE 11

BETA TRANSUS FURNACE RECORD


ENCLOSURE 11
BETA TRANSUS FURNACE
RECORD
C7000-30

N8300R:72-103
May 1972

ENCLOSURE 12

FORGE SHOP FURNACE #42 CALIBRATION

1800°F (1830°) #42 fce 10/11/71

~~30%~~

DISTANCE OF CALIBRATION THERMO-COUPLES FROM FURNACE HEARTH

1800°F

FRONT

12	11	10
9	8	7
6	5	4
3	2	1

BACK

1950° (1960°)

Front

	12	11	10
8"	1820°	1823°	1815°
27"	1833°	1840°	1831°
	9	**8**	**7**
8"	1828°	1837°	1831°
27"	1841°	1850°	1840°
	6	**5**	**4**
8"	1830°	1839°	1834°
27"	1841°	1846°	1842°
	3	**2**	**1**
8"	1832	1826	1832
27"	1840	1838	1838

Back

	12	11	10
8"	1944°	1946°	1939°
27"	1956°	1962°	1952°
	9	**8**	**7**
8"	1954°	1959°	1955°
27"	1961°	1969°	1962°
	6	**5**	**4**
8"	1959°	1960°	1956°
27"	1965°	1965°	1963°
	3	**2**	**1**
8"	1953°	1957°	1953°
27"	1962°	1963°	1962°

ENCLOSURE 12

FORGE SHOP FURNACE #42 CALIBRATION RESULTS AT 1800°F & 1950°F; MAX. TEMPERATURE VARIATION AT 1800°F WAS 35°F, BUT OVERALL TEMPERATURE WAS TOO HIGH.

N8300R:72-103
May 1972

ENCLOSURE 13

RECALIBRATION OF FURNACE #42 AFTER CONTROL INSTRUMENTATION MODIFICATIONS

Fce #42 1800°F 10/12/71

25%

FRONT

12	11	10
9	8	7
6	5	4
3	2	1

BACK

DISTANCE OF CALIBRATION THERMOCOUPLES FROM FURNACE HEARTH

	12	11	10
8"	1794°	1790°	1784°
27"	1802°	1806°	1798°

	9	8	7
8"	1805°	1813°	1806°
27"	1814°	1819°	1813°

	6	5	4
8"	1811°	1815°	1810°
27"	1816°	1821°	1821°

	3	2	1
8"	1806°	1807°	1802°
27"	1815	1815°	1815°

BACK

ENCLOSURE 13

RECALIBRATION OF FURNACE #42 AFTER CONTROL INSTRUMENTATION MODIFICATIONS. MAX. TEMPERATURE VARIATION AT 1800°F WAS 37°, i.e., 1800 ± 19°.

ENCLOSURE 14

RECALIBRATION, AT 1775°F, OF FURNACE #42

Fce #42 — 10/13/71

FRONT

10	11	12
7	8	9
4	5	6
1	2	3

BACK

1775°F

25%

DISTANCE OF CALIBRATION THERMOCOUPLES FROM FURNACE HEARTH

	10	11	12
8"	1752°	1751°	1746°
27"	1759°	1764°	1759°

	7	8	9
8"	1765°	1775°	1768°
27"	1769°	1782°	1772°

	4	5	6
8"	1781°	1788°	1785°
27"	1787°	1792°	1789°

	1	2	3
8"	1777°	1782°	1778°
27"	1788°	1789°	1791°

BACK

ENCLOSURE 1A

RECALIBRATION, AT 1775°F, OF FURNACE #42. MAX. TEMPERATURE VARIATION WAS 46°F, i.e., 1775 ± 23°F.

N8300R:72-103
May 1972

ENCLOSURE 15

CALIBRATION OF FURNACE #43

Fce # 43 10/12/71

FRONT

15	14	13
12	11	10
9	8	7
6	5	4
3	2	1

BACK

1950°F
(1955°F)

15%

DISTANCE OF CALIBRATION THERMO-COUPLE FROM FURNACE HEARTH

	15	14	13
8"	1920°	1925°	1921°
27"	1932°	1932°	1928°

	12	11	10
8"	1933°	1937°	1935°
27"	1940°	1939°	1937°

	9	8	7
8"	1939°	1946°	1942°
27"	1947°	1948°	1943°

	6	5	4
8"	1942°	1946°	1943°
27"	1948°	1951°	1948°

	3	2	1
8"	1943°	1943°	1934°
27"	1949°	1954°	1948°

BACK

ENCLOSURE 15

CALIBRATION OF FURNACE #43 USED FOR BETA FORGING OF 19 INCH SQUARE BILLET AT 2000°F.

N8300R:72-103
May 1972

ENCLOSURE 16

BILLET ULTRASONIC PROCEDURE

AGC DRAWING NO.
ANS-90295A
PURCHASE ORDER NO.
N-01365
PREPARED BY
J. M. Amaral
PHONE NO.
355-6875

ULTRASONIC PROCEDURE

AGCS 0731-9

NAME OF ULTRASONIC LAB.

RMI & TIMET

ADDRESS OF ULTRASONIC LAB.

-

NOTE: THIS FORM PROVIDES THE ESSENTIAL INFORMATION FOR:

1. Customer approval of ultrasonic procedure to be used.
2. Shop instruction for performance of the inspection
3. Report record of the procedure used.

SPECIFICATIONS	
1. Procedure Control	MIL-I-8950B
2. Acceptance Standard	ANS-90295A
3. Other	

ULTRASONIC INSTRUMENT	
Make and Model	UM 721
Recorder (if used) Make and Model	None

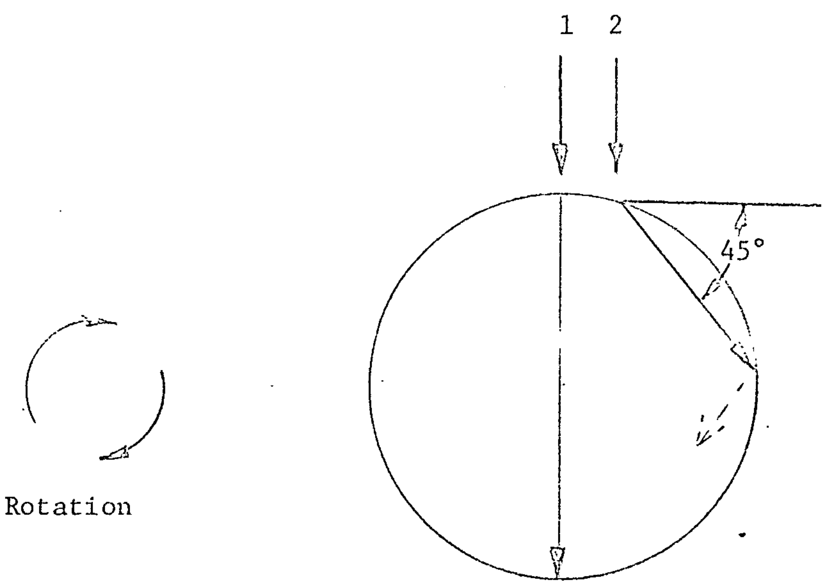
TRANSDUCERS	1	2	3
Make	Branson	Branson	
Type	LiS	LiS	
Size	3/4	3/4	
Rated Frequency	5 MHz	5 MHz	
Operated Frequency	5 MHz	5 MHz	

TEST BLOCK STANDARDS	
Material	5 Al-2.5 Sn (L) 1/2 & 1/4 Section (S) Full
Hole Size	(L) 3/64 FBH (S) .020 Section
Hole Depths	(L) .750 (4" & 2" metal travel)
Other	(S) .250 (side drilled off center @
Couplants used	Water 1/3r in 8" dia section)

INSPECTOR'S NAME	STAMP	DATE

ON SKETCH SET UP BELOW, INDICATE:

1. Shape of part.
2. Directions of scan
3. Transducer by number above, for each scan
4. Index distance: 50% of beam width
5. Scanning speed: ~ 58 sfpm



8-In. Dia. Billet

2

ENCLOSURE 17

FORGING ULTRASONIC PROCEDURES

3

AGC DRAWING NO.
1138575
PURCHASE ORDER NO.
N-02113

ULTRASONIC PROCEDURE
AGCS 0731-9

NAME OF ULTRASONIC LAB.	PREPARED BY
Sonic Testing & Engineering	J. M. Amaral
ADDRESS OF ULTRASONIC LAB.	PHONE NO.
15220 Texaco Avenue, Paramount, California	355-6875

NOTE: THIS FORM PROVIDES THE ESSENTIAL INFORMATION FOR:
1. Customer approval of ultrasonic procedure to be used.
2. Shop instruction for performance of the inspection
3. Report record of the procedure used.

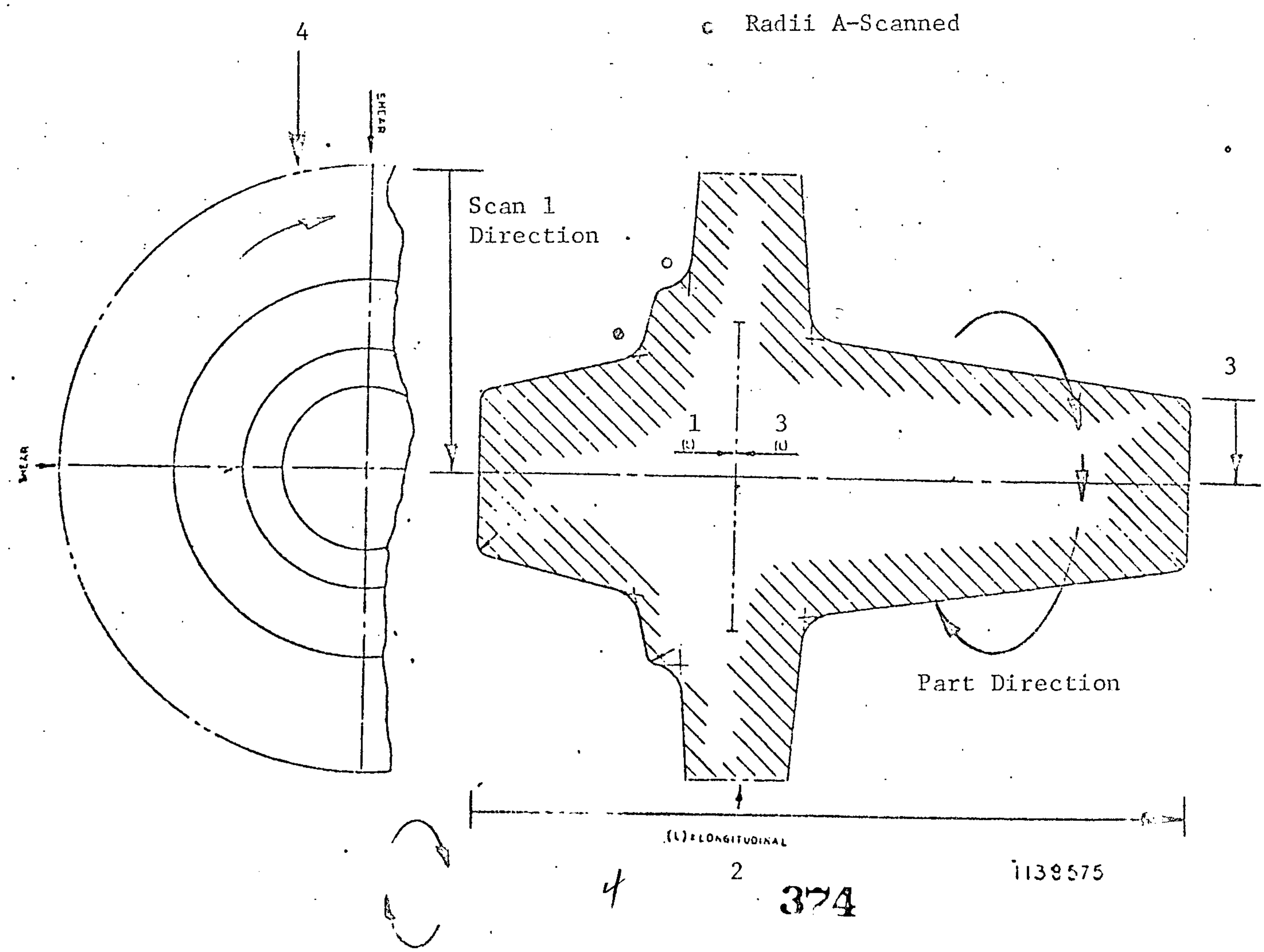
SPECIFICATIONS		ULTRASONIC INSTRUMENT	
1. Procedure Control	AGC STD. 9014	Make and Model	Sperry UM275
2. Acceptance Standard	MIL-I-8950 AAA	Recorder (if used)	C-Scan
3. Other	ANS 90297 "B"	Make and Model	Automation Industries

TRANSDUCERS	ALL 1	2	3	TEST BLOCK STANDARDS	
Make	AI			Material	Ti 5Al 2.5 Sn (Actual Part Stds)
Type	Li_2SO_4			Hole Size	1/64, 3/64 & 5/64
Size	3/4"			Hole Depths	Actual Part Thickness'
Rated Frequency	5MHz			Other	6AL-4V Std. Ref. (DAC Curve)
Operated Frequency	5MHz			Couplants used	Inhibited Water

ON SKETCH SET UP BELOW, INDICATE:
1. Shape of part.
2. Directions of scan
3. Transducer by number above, for each scan
4. Index distance
5. Scanning speed

INSPECTOR'S NAME	STAMP	DATE
Dan Norris/J. M. Amaral		11-20-71

(See General Procedure)



ULTRASONIC PROCEDURE AGCS 0731-9	AGC DRAWING NO. 1138576 PURCHASE ORDER NO. N-02113
NAME OF ULTRASONIC LAB. Sonic Testing & Engineering	PREPARED BY J. M. Amaral
ADDRESS OF ULTRASONIC LAB. 15220 Texaco Avenue, Paramount, California	PHONE NO. 355-6875

NOTE: THIS FORM PROVIDES THE ESSENTIAL INFORMATION FOR:

1. Customer approval of ultrasonic procedure to be used.
2. Shop instruction for performance of the inspection
3. Report record of the procedure used.

SPECIFICATIONS		ULTRASONIC INSTRUMENT	
1. Procedure Control	AGC STD. 9014	Make and Model	Sperry UM275
2. Acceptance Standard	MIL-I-8950 AAA	Recorder (if used)	C-Scan
3. Other	ANS 90297 "B"	Make and Model	Automation Industries

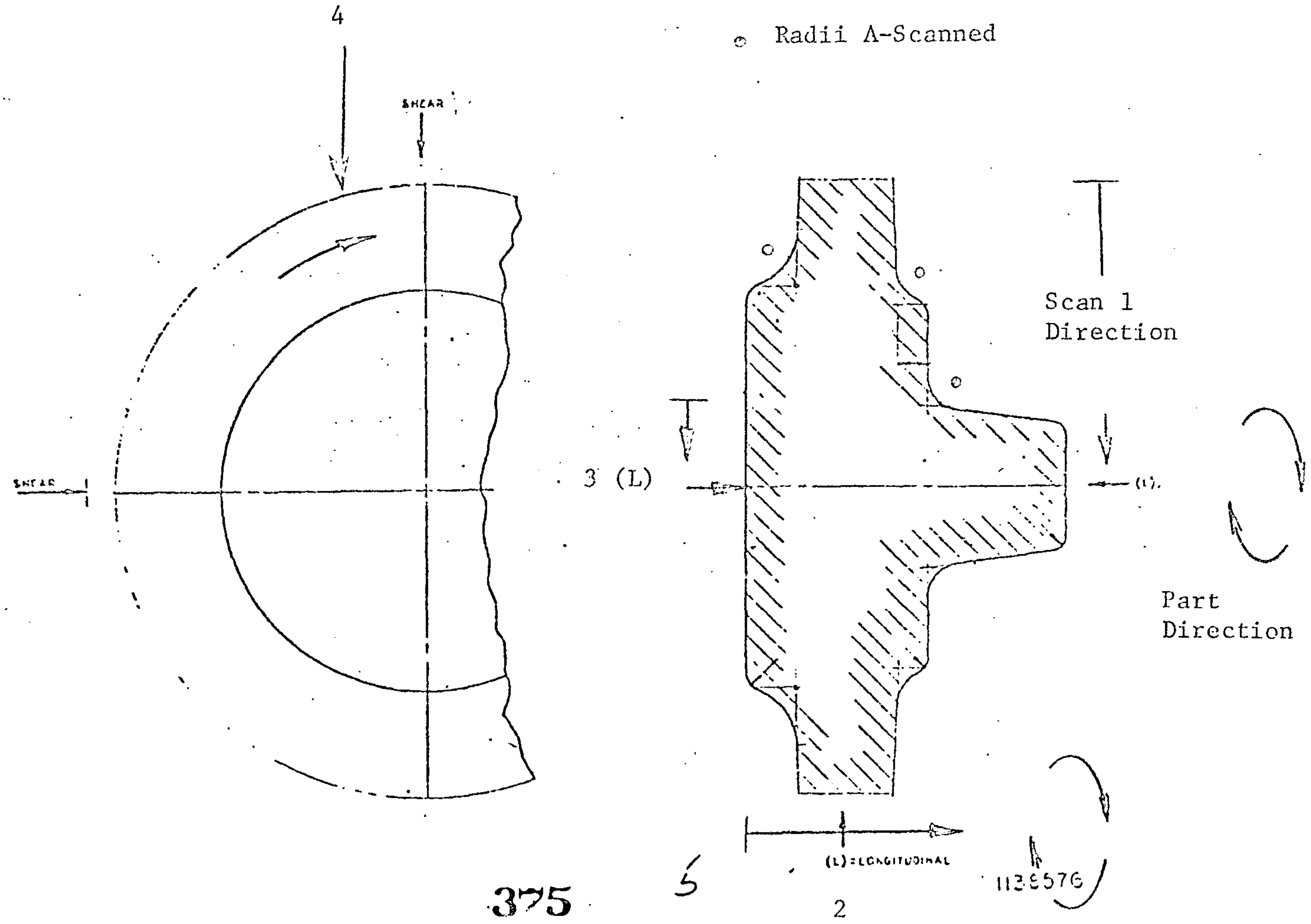
TRANSDUCERS	ALL 1	2	3	TEST BLOCK STANDARDS	
Make	AI			Material	Ti 5Al 2.5Sn (Actual Part Stds)
Type	Li_2SO_4			Hole Size	1/64, 3/64 & 5/64
Size	3/4"			Hole Depths	Actual Part Thickness'
Rated Frequency	5MHz			Other	6AL-4V Std. Ref. (DAC Curve)
Operated Frequency	5MHz			Couplants used	Inhibited Water

ON SKETCH SET UP BELOW, INDICATE:

1. Shape of part.
2. Directions of scan
3. Transducer by number above, for each scan
4. Index distance
5. Scanning speed

INSPECTOR'S NAME	STAMP	DATE
Dan Norris/J. M. Amaral		11-20-71

(See General Procedure)



ULTRASONIC PROCEDURE
AGCS 0731-9

AGC DRAWING NO.	1138577
PURCHASE ORDER NO.	N-02113
NAME OF ULTRASONIC LAB.	Sonic Testing & Engineering
PREPARED BY	J. M. Amaral
ADDRESS OF ULTRASONIC LAB.	15220 Texaco Avenue, Paramount, California
PHONE NO.	355-6875

NOTE: THIS FORM PROVIDES THE ESSENTIAL INFORMATION FOR:
1. Customer approval of ultrasonic procedure to be used.
2. Shop instruction for performance of the inspection
3. Report record of the procedure used.

SPECIFICATIONS		ULTRASONIC INSTRUMENT	
1. Procedure Control	AGC STD. 9014	Make and Model	Sperry UM725
2. Acceptance Standard	MIL-I-8950 AAA	Recorder (if used)	C-Scan
3. Other	ANS 90297 "B"	Make and Model	Automation Industries

TRANSDUCERS	All 1	2	3
Make	AI		
Type	Li_2SO_4		
Size	3/4"		
Rated Frequency	5MHz		
Operated Frequency	5MHz		

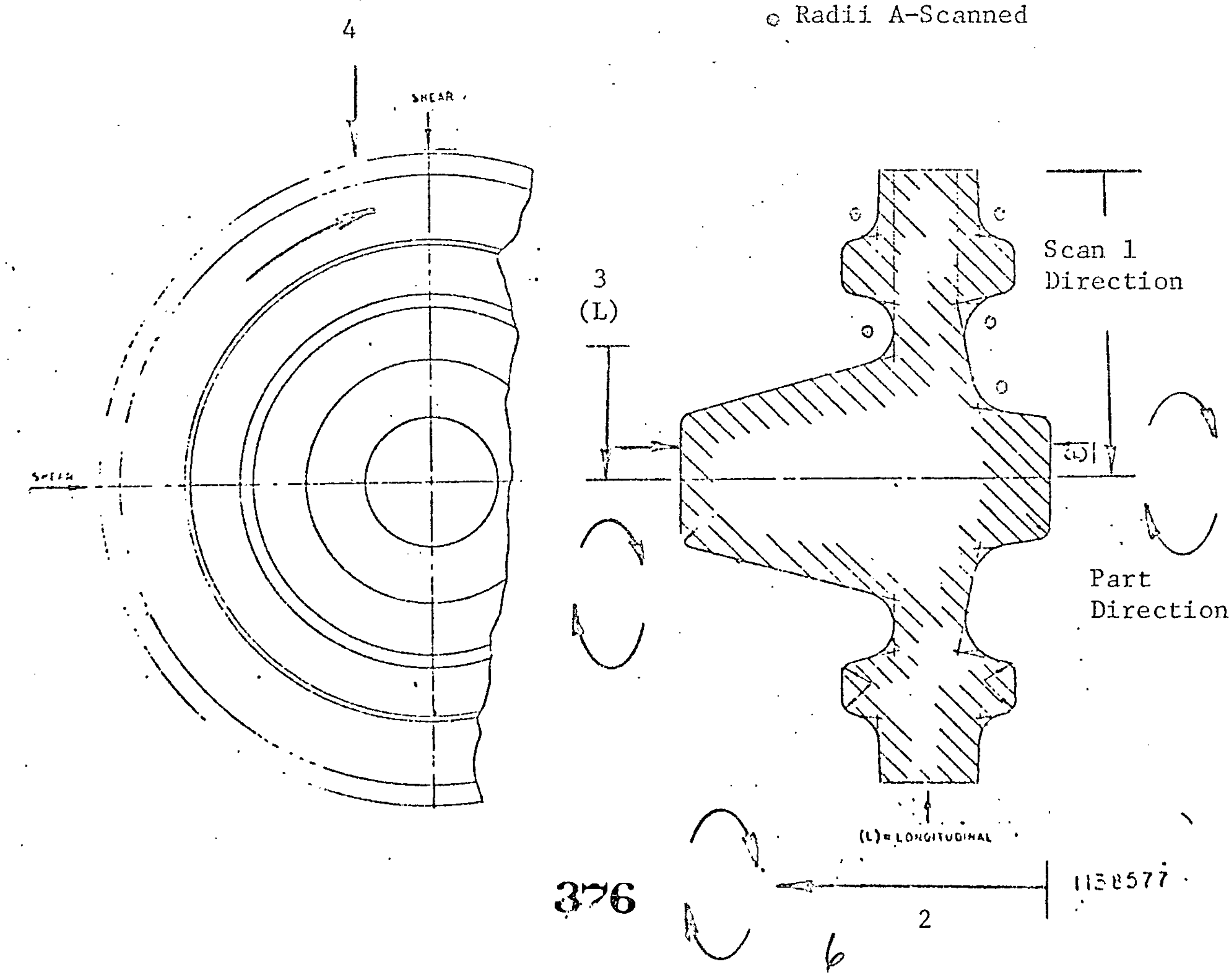
TEST BLOCK STANDARDS	
Material	Ti 5Al 2.5 Sn (Actual Part Stds)
Hole Size	1/64, 3/64 & 5/64
Hole Depths	Actual Part Thickness'
Other	6AL-4V Std. Ref. (DAC Curve)
Couplants used	Inhibited Water

INSPECTOR'S NAME	STAMP	DATE
Dan Norris/J. M. Amaral		11-20-71

ON SKETCH SET UP BELOW, INDICATE:
1. Shape of part.
2. Directions of scan
3. Transducer by number above, for each scan
4. Index distance
5. Scanning speed

(See General Procedure)

o Radii A-Scanned



AGC DRAWING NO.
1138578
PURCHASE ORDER NO.
N-02113
PREPARED BY
J. M. Amaral
PHONE NO.
355-6875

ULTRASONIC PROCEDURE

AGCS 0731-9

NAME OF ULTRASONIC LAB.

Sonic Testing & Engineering

ADDRESS OF ULTRASONIC LAB.

15220 Texaco Avenue, Paramount, California

NOTE: THIS FORM PROVIDES THE ESSENTIAL INFORMATION FOR:

1. Customer approval of ultrasonic procedure to be used.
2. Shop instruction for performance of the inspection
3. Report record of the procedure used.

SPECIFICATIONS		ULTRASONIC INSTRUMENT	
1. Procedure Control	AGC STD. 9014	Make and Model	Sperry UM275
2. Acceptance Standard	MIL-I-8950 AAA	Recorder (if used)	C-Scan
3. Other	ANS 90297 "B"	Make and Model	Automation Industries

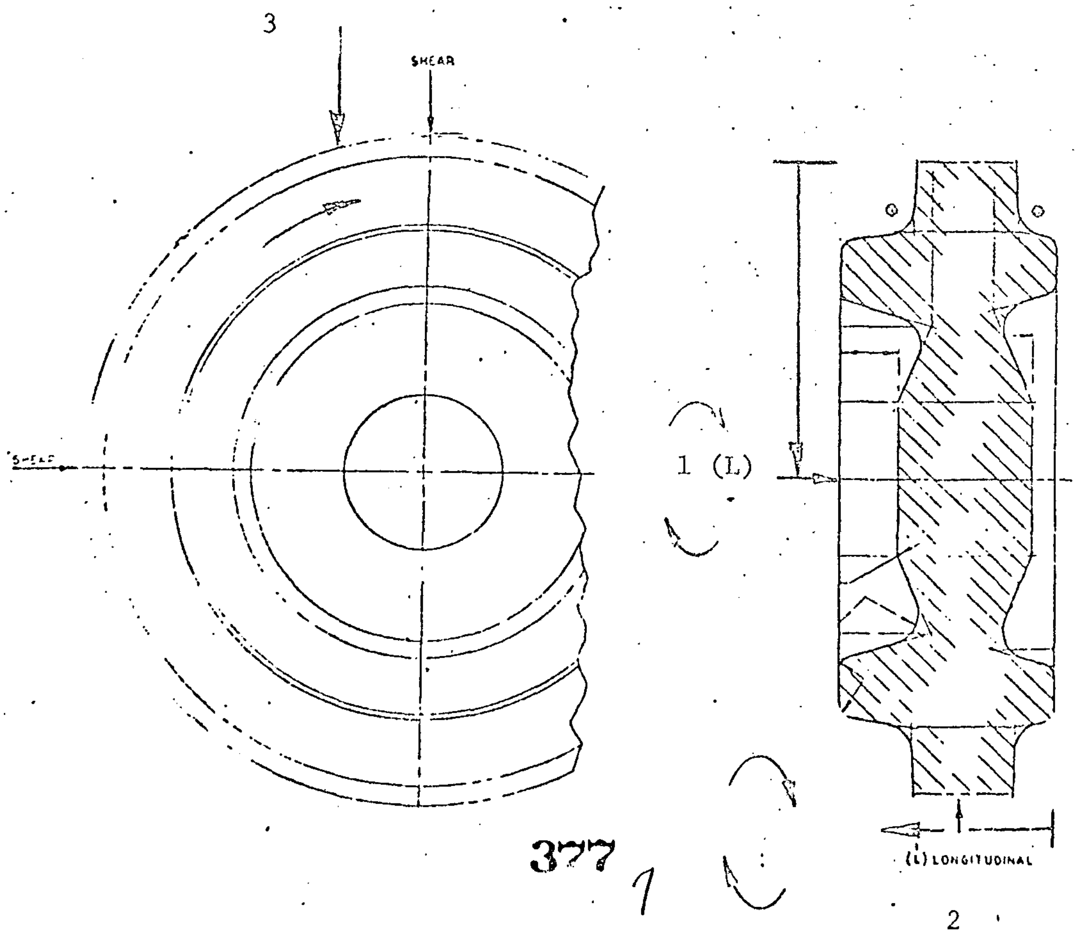
TRANSDUCERS	ALL 1	2	3	TEST BLOCK STANDARDS	
Make	AI			Material	Ti 5Al 2.5 Sn (Actual Part Stds)
Type	$Li_2\ SO_4$			Hole Size	1/64, 3/64 & 5/64
Size	3/4"			Hole Depths	Actual Part Thickness'
Rated Frequency	$5MH_z$			Other	6AL-4V Std. Ref. (DAC Curve)
Operated Frequency	$5MH_z$			Couplants used	Inhibited Water

ON SKETCH SET UP BELOW, INDICATE:
1. Shape of part.
2. Directions of scan
3. Transducer by number above, for each scan
4. Index distance
5. Scanning speed

INSPECTOR'S NAME	STAMP	DATE
Dan Norris/J. M. Amaral		11-20-71

(See General Procedure)

⊙ Radii A-Scanned



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1

1138578

ULTRASONIC PROCEDURE AGCS 0731-9	AGC DRAWING NO. 1133579 PURCHASE ORDER NO. N-02113
NAME OF ULTRASONIC LAB. Sonic Testing & Engineering	PREPARED BY J. M. Amaral
ADDRESS OF ULTRASONIC LAB. 15220 Texaco Avenue, Paramount, California	PHONE NO. 355-6875

NOTE: THIS FORM PROVIDES THE ESSENTIAL INFORMATION FOR:
1. Customer approval of ultrasonic procedure to be used.
2. Shop instruction for performance of the inspection
3. Report record of the procedure used.

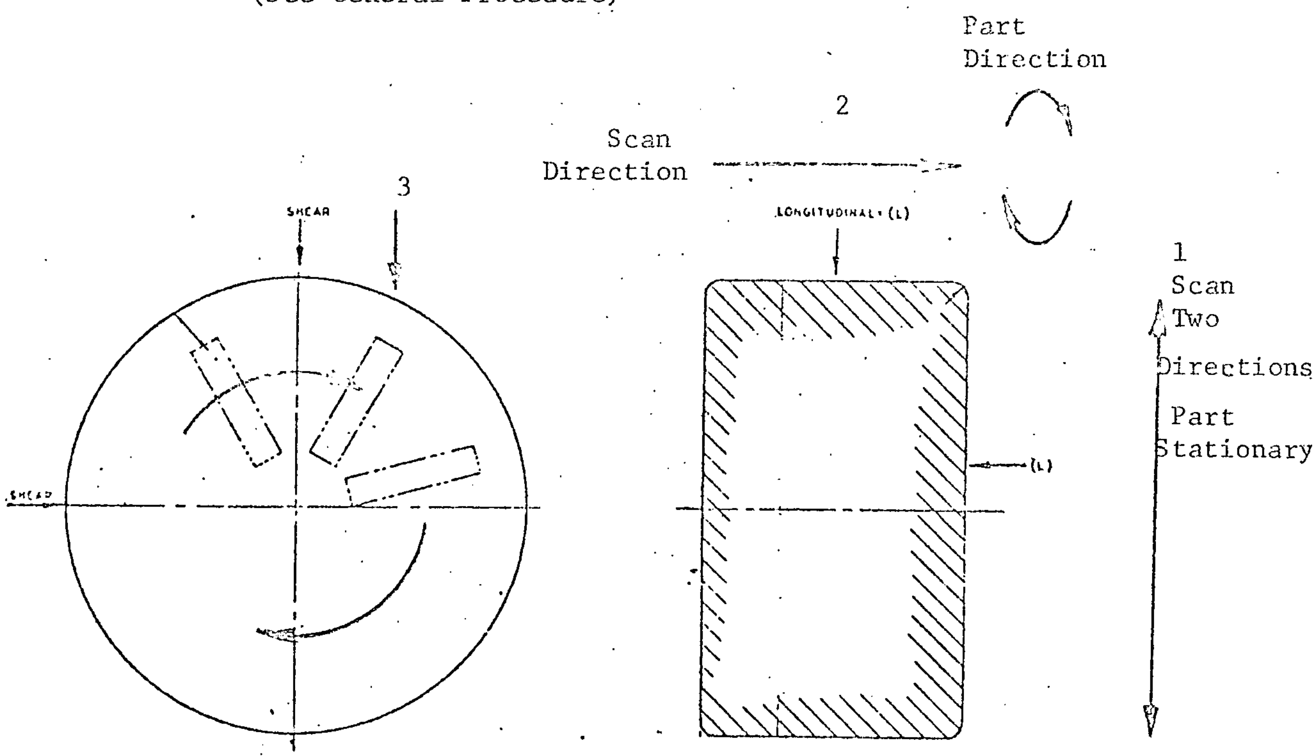
SPECIFICATIONS		ULTRASONIC INSTRUMENT	
1. Procedure Control	AGC STD. 9014	Make and Model	Sperry UM725
2. Acceptance Standard	MIL-I-8950 AAA	Recorder (if used)	C-Scan
3. Other	ANS 90297 "B"	Make and Model	Automation Industries

TRANSDUCERS	1	2	3	TEST BLOCK STANDARDS	
Make	AI	AI	AI	Material	Ti 5Al 2.5 Sn (Actual Part Stds)
Type	$Li_2 SO_4$	$Li_2 SO_4$	$Li_2 SO_4$	Hole Size	1/64, 3/64 & 5/64
Size	3/4"	3/4"	3/4"	Hole Depths	Actual Part Thickness'
Rated Frequency	$5MH_z$	$5MH_z$	$5MH_z$	Other	6AL-4V Std. Ref. (DAC Curve)
Operated Frequency	$5MH_z$	$5MH_z$	$5MH_z$	Couplants used	Inhibited Water

INSPECTOR'S NAME	STAMP	DATE
Dan Norris/J. M. Amaral		11-20-71

ON SKETCH SET UP BELOW, INDICATE:
1. Shape of part.
2. Directions of scan
3. Transducer by number above, for each scan
4. Index distance
5. Scanning speed

(See General Procedure)



4

1138579

N8300R:72-103
May 1972

ENCLOSURE 18

FORGING RADIOGRAPHIC INSPECTION PROCEDURE

I

ARCTURUS MFG. CORP. OXNARD, CALIF.	ARCTURUS PROCESS PROCEDURE	ANSC-XR-1000
	Radiographic Inspection Procedure for ANSC P/N 1138577-1 "D" Arcturus Die 2917	ISSUED 8/30/71
		REVISION
		PAGE 1 of 1

1.0 SCOPE: This document establishes the procedures for the radiographic inspection of the following parts:

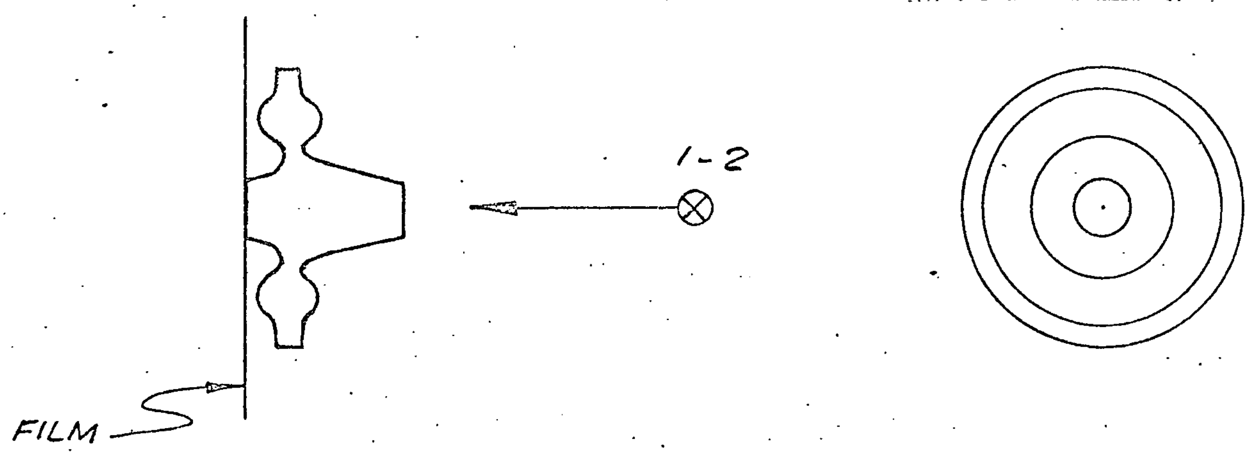
ANSC P/N	Arcturus Die #
1138579-1 C	X-292
1138579-2 C	X-293
1138575-1 D	2915
1138576-1 E	2916
1138577-1 D	2917
1138578-1E	2918

2.0 REFERENCE DOCUMENTS: Mil-Std-453, ANSC-09297"B".

3.0 PROCEDURE: The following lists the procedure which shall be applied to the radiographic inspection of the above referenced part number.

a. Radiation source - 2 MEV-X-ray Unit
b. Film - AGFA-Gevaert D4 and D7
c. Intensifying Screens - .010 Lead
d. Blocking or Masking - None
e. Minimum source to film distance - 40"
f. Penetrameter - Mil. Std. 453 (Titanium)
g. Quality level - 2-2T
h. Density - 1.8 to 3.2
i. Development of Film - Automatic Developing
j. Number of views - 2

X-RAY SKETCH:



4.0 ACCEPTANCE CRITERIA: Acceptance criteria shall be per ANSC-9032-1.

N8300R:72-103
May 1972

ENCLOSURE 19

DRM 04.08

381

DRM: 04.08
DATE: 3 DECEMBER 1971
PAGE: 1 OF 8

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

MATERIAL	FORM	CONDITION	PROPERTY	DATA CATEGORY	PAGE
Ti 5Al-2.5Sn ELI	DIE FORGINGS	ANNEALED	TENSILE ULTIMATE STRENGTH	A	2
			TENSILE YIELD STRENGTH	A	3
			ELONGATION	A	4

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SYMBOLS USED ON PAGES 2-4

m = EFFECTIVE SAMPLE SIZE

f = DEGREES OF FREEDOM FOR COMBINED STANDARD DEVIATION, σ_T

k = 99/95 LOWER TOLERANCE LIMIT FACTOR FOR m AND f

PREPARED BY: M Shev

REVIEWED BY:

MATERIALS

RELIABILITY A. J. McDermid

CLASSIFICATION:

UNCLASSIFIED

PER: M Shev

DATE: 12-3-71

[illegible] Ti-5Al-2.5Sn ELI FORM DIE FORGINGS CONDITION ANNEALED

[illegible] 90295A, 90296A, 90297B DIRECTION ALL

[illegible] TENSILE ULTIMATE STRENGTH, KSI

TEMP °F	NO. OF OBSERVATIONS	NO. OF FORGINGS	NO. OF HEATS	VARIANCE FORGING-TO-FORGING	VARIANCE WITHIN FORGINGS	VARIANCE TOTAL s_T^2	m	f	MEAN ✩ VALUE $\bar{X}$	k	s_T	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
RT	60	15	2	2.88	1.06	3.94	15.0	17.0	118.9	3.39	1.98	112.2	A	1

383

✩ LOWEST MEAN OF THE 4 CONFIGURATIONS

25

MATERIAL Ti 5AL-2.5SN ELI FORM DIE FORGINGS CONDITION ANNEALED

SPECIFICATIONS 90295A, 90296A, 902973 DIRECTION ALL

PROPERTY TENSILE YIELD STRENGTH, KSI

TEMP °F	NO. OF OBSERVATIONS	NO. OF FORGINGS	NO. OF HEAT	VARIANCE			m	f	MEAN ☆ VALUE $\bar{X}$	k	s_T	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
				FORGING-TO-FORGING	WITHIN FORGINGS	TOTAL s_T^2								
RT	60	15	2	3.23	1.42	4.65	15.6	18.1	110.6	3.36	2.16	103.3	A	1

384

☆ LOWEST MEAN OF THE 4 CONFIGURATIONS

MATERIAL Ti 5AL-2.5SN ELI FORM DIE FORGINGS CONDITION ANNEALED

SPECIFICATIONS 90295A, 90296A, 90297B DIRECTION ALL

PROPERTY ELONGATION, %

				VARIANCE										
TEMP °F	NO. OF OBSERVATIONS	NO. OF FORGINGS	NO. OF HEAT	FORGING-TO-FORGING	WITHIN FORGINGS	TOTAL s_T^2	n	f	MEAN * VALUE $\bar{X}$	k	s_T	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
RT	60	15	2	0.49	1.48	1.97	27.5	41.5	14.1	2.93	1.40	10.0	A	1

385

* LOWEST MEAN OF THE 4 CONFIGURATIONS

I. TEST DESCRIPTION (Reference 1)

Tensile specimens were machined from fifteen rotor forgings which were die-forged by Arcturus Manufacturing Company. The forgings represented four different parts for TPA S/N 1. From each forging, three tangentially oriented and one radially oriented specimens were tested.

The forgings were made from three titanium billets of which two ("T" and "T1") came from RMI Heat 804722 and the third ("B") from TMCA Heat K8930. The heats were produced in accordance with ANSC Spec. 90295A and 90296A and the forgings were produced per ANSC Spec. 90297B. The test matrix is shown in the following table, which also shows average tensile properties for the fifteen forgings.

ARCTURUS DIE NO.	ANSC P/N	HEAT	ARCTURUS FORGING S/N	NO. OF * SPECIMENS	AVERAGE PROPERTIES UTS (KSI)	YTS (KSI)	ELONGATION (%)
2915	1138575	TMCA	8	4	120.8	112.0	16.0
		RMI	11	4	119.0	111.0	18.5
		RMI	12	4	117.2	109.5	16.8
2918	1138578	RMI	11	4	119.0	111.2	18.2
		RMI	12	4	120.0	112.5	18.2
		RMI	13	4	121.0	113.2	16.8
		RMI	14	4	120.0	114.5	16.8
		RMI	15	4	120.0	114.5	15.8
2916	1138576	TMCA	5	4	120.0	111.8	14.8
		RMI	6	4	122.5	114.0	15.2
		RMI	7	4	116.0	107.0	13.8
		RMI**	8	4	117.2	109.8	14.0
2917	1138577	TMCA	4	4	120.8	112.0	14.2
		TMCA	5	4	121.2	112.0	14.0
		TMCA	6	4	122.2	113.8	14.0

* 3 Tangential, 1 Radial

** Billet "T1"; all others from RMI heat are Billet "T".

II. DATA ANALYSIS

The possible sources of variation in the above test plan are:

1. Directions (tangential vs. radial)
2. Configurations (i.e. part numbers or dies)
3. Heats or billets
4. Differences among forgings of the same configuration
5. Differences among specimens from the same forging.

The effects of configurations and of heats are partially confounded or confused with each other; for example, it is impossible to determine whether an observed difference in properties between P/N's 1138578 and 1138577 is due to the different configurations or to a difference between the two heats.

Primary Analysis of Variance showed that there was no difference between the tangential and radial orientations. Therefore the specimens from each forging were combined into a single group of four. There was, however, for all three tensile properties, significant forging-to-forging variability, which was further partitioned into two components, within and between configurations. The Analysis of Variance tables for the three properties are shown in Table I. This analysis shows that configuration differences are significant only for elongation.

Reference (1) points out that specimens from P/N's 1138576 and 1138577 were tested on a different day and on a different testing machine from the specimens taken from the other two configurations. This factor rather than true configuration differences probably accounts for the observed difference in elongation between the two pairs of configurations.

Although isolation of a heat-to-heat component of variance is precluded because of confounding with configurations, inspection of the table on Page 5 shows no apparent difference by heats in those cases where billets from both heats were used to make the same configuration.

The calculation of design allowables followed the primary procedure of Reference (2) with forgings representing "Lots". The variances from the two random sources of variation, "Specimens within Forgings" and "Forgings within Configurations", were combined to obtain the standard deviation s_T. The appropriate effective sample size and degrees of freedom (m and f) were determined by means of the Satterthwaite approximation. The corresponding 99/95 tolerance limit factor, k, was obtained from the computer program TFAC** on the G.E. computer. The design allowables were calculated as $\bar{X}-ks_T$, in which $\bar{X}$ is the mean for each of the four configurations. Since these averages do not differ greatly, only the lowest of the four is reported, and the allowables are considered to apply to any of the four TPA parts, or to any similar forgings.

The data are categorized as "A".

III. REFERENCES

1. Materials Memorandum MS130:0230 from P. P. Dessau to H. Derow, dated 10 November 1971, Subject: "Die-Forged Ti-5Al-2.5Sn ELI Data from TPA S/N 1 Tests".

2. NERVA Program Procedure R103-NRP-503, "Statistical Analysis of Material Test Data".

TABLE I

ANALYSIS OF VARIANCE TABLES

TENSILE PROPERTY	SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
ULTIMATE STRENGTH (KSI)	CONFIGURATIONS	51.747	3	17.249	1.37
	FORGINGS (WITHIN CONFIGURATIONS)	138.353	11	12.578	11.91 **
	SPECIMENS (WITHIN FORGINGS)	47.500	45	1.056	
	TOTAL	237.600	59		
YIELD STRENGTH (KSI)	CONFIGURATIONS	79.062	3	26.354	1.84
	FORGINGS (WITHIN CONFIGURATIONS)	157.773	11	14.343	10.12 **
	SPECIMENS (WITHIN FORGINGS)	63.750	45	1.417	
	TOTAL	300.585	59		
ELONGATION (%)	CONFIGURATIONS	121.278	3	40.426	11.76 **
	FORGINGS (WITHIN CONFIGURATIONS)	37.818	11	3.438	2.33 *
	SPECIMENS (WITHIN FORGINGS)	66.500	45	1.478	
	TOTAL	225.600	59		

* SIGNIFICANT, .05 LEVEL

** SIGNIFICANT, .01 LEVEL

N8300R:72-103
May 1972

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ENCLOSURE 20

DRM 04.10R1

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AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

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* PANCAKE FORGINGS @ -423°F ONLY

** RT IN GH_2, 100 PSI; -160°F IN GH_2, 1200 PSI; -423°F IN LH_2

NOTE: THIS REVISION SUPERSEDES DRM 04.10 DATED 30 MARCH 1972, WHICH INCLUDED ONLY STATIC FRACTURE TOUGHNESS AT ROOM TEMPERATURE. THE DATA INCLUDED IN THE ORIGINAL DRM HAS BEEN COMPLETELY INCORPORATED INTO THE REVISION.

EXPLANATION OF SYMBOLS ON PAGES 2 - 7:

- s = STANDARD DEVIATION (STANDARD ERROR OF ESTIMATE)
- n_e = EFFECTIVE SAMPLE SIZE
- f = DEGREES OF FREEDOM FOR s
- k = 99/95 ONE-SIDED TOLERANCE LIMIT FACTOR

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PREPARED BY: M Shew

REVIEWED BY: ____________

CLASSIFICATION:

UNCLASSIFIED

PER M Shew

DATE 5/4/72

MATERIAL Ti 5Al 2.5 Sn ELI FORM DIE FORGINGS/PANCAKE FORGINGS CONDITION ANNEALED

SPECIFICATIONS ANS 90297 B

PROPERTY FRACTURE TOUGHNESS, K_{IC}, KSI $\sqrt{IN.}$

A. DIE FORGINGS

TEMP °F	MEAN	s	n	f	k	99/95 DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
RT	100.0	4.23	12	12	3.67	84.5	C	1, 2
-160	85.4	4.23	2	12	4.20	67.6	C	2
-423	54.3	4.23	2	12	4.20	36.5	C	2

B. PANCAKE FORGINGS

TEMP °F	MEAN	s	n	f	k	99/95 DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
-423	69.4	4.23	1	12	4.65	49.7	C	2

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MATERIAL Ti 5Al 2.5Sn ELI FORM DIE FORGINGS CONDITION ANNEALED

SPECIFICATIONS ANS 90297 B

PROPERTY NUMBER OF CYCLES TO VARIOUS STRESS INTENSITY (Ki) VALUES

		LOG OF CYCLES						NO. OF CYCLES			
TEMP °F	Ki KSI-$\sqrt{IN}$	MEAN	s	k	n_e	f	99/95 LOWER LIMIT	50% POINT	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
RT	20	4.372	0.138	3.63	6	15	3.871	23528	7431	C	2
	30	3.922		3.53	10		3.435	8352	2722		
	40	3.501		3.48	14		3.021	3167	1049		
	50	3.108		3.49	13		2.626	1283	423		
	60	2.744		3.57	8		2.251	555	178		
	70	2.409		3.68	5		1.901	256	80		
	80	2.102		3.86	3		1.569	127	37		
-160	20	4.391		3.63	6		3.890	24594	7764	C	2
	30	3.920		3.51	11		3.436	8317	2727		
	40	3.478		3.46	16		3.001	3004	1001		
	50	3.064		3.49	13		2.582	1159	382		
	60	2.679		3.57	8		2.186	478	154		
-423	20	4.706		5.40	0.42*		3.961	50811	9137	C	2
	30	3.890		4.05	2		3.331	7774	2143		
	40	3.104		4.50	1		2.483	1270	304		

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* NORMALLY, n_e IS ROUNDED TO THE LARGEST INTEGER NOT GREATER THAN THE CALCULATED VALUE. IN THIS CASE SUCH A ROUNDING PROCEDURE WOULD HAVE YIELDED n_e=0 FOR WHICH NO k VALUE WOULD EXIST. THEREFORE THE CALCULATED FRACTIONAL VALUE OF 0.42 WAS USED.

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MATERIAL Ti 5Al 2.5Sn ELI FORM FORGINGS CONDITION ANNEALED

SPECIFICATIONS ANS 90297 B

PROPERTY CYCLIC FRACTURE TOUGHNESS (Ki) KSI-$\sqrt{IN}$

A. DIE FORGINGS

TEMP °F	NO. OF CYCLES	Ki (KSI - $\sqrt{IN}$) MEAN	s	n_e	f	k	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
RT	100	83.5	3.95	2	15	4.05	67.5	C	2
	1000	52.9	3.69	12	15	3.50	40.0	C	
	10000	28.2	3.44	9	15	3.55	16.0	C	
-160	1000	51.6	3.31	12	15	3.50	40.0	C	
	10000	28.3	2.92	10	15	3.53	18.0	C	
-423	1000	41.3	1.40	1	15	4.50	35.0	C	
	10000	28.6	1.58	2	15	4.05	22.2	C	

B. PANCAKE FORGINGS

TEMP °F	NO. OF CYCLES	MEAN	s	n_e	f	k	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
-423	1000	46.2	1.40	1	15	4.50	39.9	D*	2
	10000	33.6	1.58	1	15	4.50	26.5	C	

* SEE PAGE 15.

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MATERIAL Ti 5Al 2.5Sn ELI FORM DIE FORGINGS CONDITION ANNEALED

SPECIFICATIONS ANS 90297 B

PROPERTY CRACK GROWTH RATE (da/dN), MICRO-INCHES/CYCLE @ RT

	LOG (CRACK GROWTH RATE)						CRACK GROWTH RATE			
Ki (KSI-√IN)	MEAN	s	n_e	f	k	99/95 UPPER LIMIT	50% POINT	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
20	0.696	.156	9	103	2.98	1.161	5	14	C	2
30	1.314		21		2.81	1.752	21	57		
40	1.751		46		2.73	2.177	56	150		
50	2.091		75		2.69	2.511	123	324		
60	2.369		74		2.69	2.789	234	615		
70	2.603		43		2.71	3.026	401	1061		
80	2.806		37		2.75	3.235	640	1718		
90	2.986		27		2.78	3.420	967	2628		
100	3.234		16		2.86	3.680	1708	4788		
110	3.504		26		2.78	3.938	3188	8663		
120	3.751		19		2.83	4.192	5636	15577		
130	3.979		10		2.95	4.439	9518	27942		
140	4.189		6		3.09	4.671	15461	46886		
150	4.385		4		3.24	4.890	24289	77703		

MATERIAL Ti 5Al-2.5Sn ELI FORM DIE FORGINGS CONDITION ANNEALED

SPECIFICATIONS ANS 90297 B

PROPERTY CRACK GROWTH RATE (da/dN), MICRO-INCHES/CYCLE @ -160°F, -423°F

		LOG (CRACK GROWTH RATE)						CRACK GROWTH RATE			
TEMP °F	Ki (KSI-$\sqrt{IN}$)	MEAN	s	n_e	f	k	99/95 UPPER LIMIT	50% POINT	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
-160	30	1.045	.0887	6	41	3.23	1.331	11	21	C	2
	40	1.534		14		3.04	1.803	34	64		
	50	1.913		30		2.95	2.174	82	149		
	60	2.222		42		2.92	2.481	167	303		
	70	2.484		33		2.94	2.745	305	556		
	80	2.711		21		2.99	2.976	514	947		
	90	2.911		14		3.04	3.181	815	1516		
-423	30	1.171	0.327	5	16	3.64	2.361	15	230	C	2
	35	1.501		9		3.51	2.649	32	445		
	40	1.998		12		3.46	3.129	100	1347		
	45	2.601		11		3.47	3.736	399	5441		
	50	3.269		7		3.56	4.433	1858	27109		
	55	3.979		4		3.71	5.192	9533	155657		
	60	4.715		2		4.01	6.026	51984	1062360		

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MATERIAL Ti 5Al-2.5Sn ELI FORM PANCAKE FORGINGS CONDITION ANNEALED

SPECIFICATION ANS 90297 B

PROPERTY CRACK GROWTH RATE (da/dN), MICRO-INCHES/CYCLE @ -423°F

	LOG (CRACK GROWTH RATE)						CRACK GROWTH RATE			
Ki (KSI-$\sqrt{IN}$)	MEAN	s	n_e	f	k	99/95 UPPER LIMIT	50% POINT	DESIGN ALLOWABLE	DATA CATEGORY	SOURCE REFERENCE
30	0.378	.327	2	16	4.01	1.689	2	49	C	2
35	0.707		3		3.82	1.956	5	90		
40	1.204		4		3.71	2.417	16	261		
45	1.807		6		3.59	2.981	64	957		
50	2.475		6		3.59	3.649	299	4456		
55	3.185		6		3.59	4.359	1532	22852		
60	3.921		4		3.71	5.134	8339	136198		

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1. TEST DESCRIPTION

This DRM is based upon work performed by the Boeing Aerospace Group, Seattle, Washington under ANSC P. O. N-01499. (Room temperature static fracture toughness data obtained by Metallurgical Testing Corporation under ANSC P. O. N-02243 is also included in this DRM and has been combined with the corresponding Boeing data. The Metallurgical Testing Corp. data was the subject of the original DRM 04.10 which is being superseded by this revision. Material from the same two lots were used in both programs).

Two heats of Ti 5Al-2.5Sn ELI per ANSC Specification ANS 90297B were used for the test program. Heat 804722 produced by RMI, was used to fabricate die forgings. Heat K8930, produced by TMCA, was used to fabricate both die and pancake forgings. These heats were specially prepared for ANSC. All forgings were produced by Arcturus Manufacturing Company, Oxnard, Calif.

Fracture toughness specimens were fabricated from the die and pancake forgings so as to maintain the flaw propagation direction of the specimens parallel to the radial direction. A total of 24 specimens were fabricated and the testing was conducted at room temperature, -160°F and -423°F. The room temperature and -160°F tests were conducted in GH_2 and GHe; the -423°F tests were conducted in LH_2. The 24 specimen test program was designed as an interim program to provide statistical data from which a major test program would be developed. The test matrix for the interim program was designed to be as small as possible consistent with this goal.

Both static (K_{IC}) and cyclic (Ki) fracture toughness tests were conducted. One static test and two cyclic tests were performed for each of the die and pancake forgings. From the results, a Ki versus number of cycles to failure curve was developed at each temperature. In addition, instantaneous crack growth rate (crack growth per cycle) data was developed for each Ki test. The test matrix is shown in Table 1.

Test results were as follows:

Test Temp, °F	Specimen No.	No. of Cycles	K_{IC} or Ki (KSI - $\sqrt{}$ IN)
RT	880471	1 (K_{IC})	108.4
	880486	1 "	104.7
	880489	1 "	97.4
	880472	191	75.9
	880473	393	56.3
	880473	24377	19.2
	880474	2719	44.2
	880487	1500	48.6
	880488	3517	35.1
	880488	22000	18.8
	880490	25926	19.2
	880491	100	83.8
	880491	1882	46.9

Test Temp, °F	Specimen No.	No. of Cycles	K_{IC} or Ki (KSI - $\sqrt{IN}$)
-160	880477	1 (K_{IC})	84.9
	880483	1 "	86.0
	880478	2738	42.3
	880479	9737	30.3
	880479	23502	22.3
	880484	2540	43.4
	880485	606	57.7
	880485	1926	44.8
-423	880476	1 (K_{IC})	55.2
	880480	1 "	53.4
	880492 *	1 "	69.4
	880475	1609	36.7
	880482	1601	36.7
	880481	12867	25.8
	880493 *	10347	33.6

* Pancake Forgings

TABLE 1

MILL	FORGING P/N	SHAPE	S/N	SPECIMEN	NUMBER OF OBSERVATIONS: R.T. (100 PSI GH_2) STATIC	R.T. CYCLIC	R.T. CRACK GROWTH	-160 (1200 PSI GH_2) STATIC	-160 CYCLIC	-160 CRACK GROWTH	-423 (LH_2) STATIC	-423 CYCLIC	-423 CRACK GROWTH
TMCA	1138575	RING	8	880471	1								
TMCA	1138575	"	8	880472		1	15						
TMCA	1138575	"	8	880473		2	20						
RMI	1138575	"	12	880474*		1	16						
RMI	1138575	"	12	880475								1	3
RMI	1138575	"	12	880476							1		
TMCA	1138576	"	5	880477				1					
TMCA	1138576	"	5	880478					1	13			
TMCA	1138576	"	5	880485*					2	8			
RMI	1138576	"	6	880480							1		
RMI	1138576	"	6	880481								1	6
RMI	1138576	"	6	880482								1	4
TMCA	1138577	"	4	880479					2	16			
TMCA	1138577	"	4	880483				1					
TMCA	1138577	"	4	880484					1	12			
RMI	1138578	"	11	880486	1								
RMI	1138578	"	11	880487		2	16						
RMI	1138578	"	11	880488		2	19						
RMI	1138578	CENTER	11	880489	1								
RMI	1138578	"	11	880490		1	18						
RMI	1138578	"	11	880491		2	19						
TMCA	1138579 (PANCAKE)	SLICE	3	880492							1		
	"	"	4	880493								1	7
	"	"	5	880494								1**	-

* IN GASEOUS HELIUM; ALL OTHERS IN H_2 ** FAILED ON INCREASING LOAD; NO CYCLIC DATA OBTAINED

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2. DATA ANALYSIS

a. Static Fracture Toughness

The Boeing K_{IC} data consisted of 3 tests at room temperature, two at -160°F, and three at -423°F. All specimens were prepared from die forgings except one at -423°F which was from a pancake forging.

Results on nine specimens tested at room temperature by Metallurgical Testing Corporation under ANSC P.O. N-02243 (Reference 1) were also included in this analysis. These specimens were prepared from the same two material lots as those tested by Boeing. There was no significant difference in fracture toughness between the two material lots and therefore the two groups were combined.

Despite the fact that the Metallurgical Testing specimens were tested in air, their fracture toughness did not differ significantly from that of the Boeing specimens, tested in hydrogen. The within-group variabilities were also homogeneous and the two groups were combined to form a single group of 12 observations at room temperature.

Within group variabilities were found to be homogeneous over all temperatures, and accordingly a pooled standard deviation, s, based on 12 degrees of freedom, was calculated. The design allowables at each temperature were calculated in the usual manner as $\bar{X}$ - ks.

The pancake forging specimen had a much higher K_{IC} than the die forging specimens, a result expected both from previous testing experience and from comparative microstructure. This difference is also seen in the cyclic tests and in the crack growth rate data. The K_{IC} for the pancake forging is shown separately. It was assumed that the pooled standard deviation calculated for die forgings would also apply to pancake forgings.

b. Cyclic Fracture Toughness.

The method of regression analysis was used for the cyclic Ki data, employing the G. E. computer program MULFIT. In this analysis, the cyclic life is expressed as a function of the stress intensity, Ki. Because of the small number of observations at each temperature, data for all three temperatures were included in a single regression equation in which temperature occurs as a second independent variable.

Theoretically, the static tests could be included in this same regression equation as the cyclic tests since K_{IC} is merely Ki after one cycle. However, no simple function could be found that would efficiently fit both groups of data and therefore the static data were handled separately as shown above. The use of the MULFIT program consisted of trying various functions of Ki, temperature and cycle life to determine a model which would fit the experimental data with a minimum standard error of estimate, s_e. The following results were obtained:

$n = 20$; $s_e = .138$ (log units); $R^2 = .959$

Regression Equation:

$$\text{Log } y - 5.277 = .0494\, x + 1.432 \times 10^{-4}\, x^2 + 42.378\, (1/_R) - 1.4539\, (x/R)$$

where x = stress intensity (Ki), KSI $-\sqrt{\text{in.}}$

R = test temperature, °R

y = number of cycles.

This equation includes the quadratic function of Ki, the reciprocal function of temperature, and a final interaction term which expresses the differences in response for the three different temperatures.

The equation was used to calculate the expected number of cycles for various stress intensity levels at the three temperatures. These are shown on Page 3, both in log and anti-log form. The 99/95 lower limits were calculated as log y - ks, where the tolerance limit factor k is based upon the effective sample size, n_e, and the degrees of freedom, f, associated with s. Finally the lower limit was converted to the anti-log form.

Probably a more useful representation of the same data is given on Page 4. Here, the expected stress intensity after various numbers of cycles are shown, with corresponding design allowables. These values were obtained by back-solving the regression equation for both mean and lower limit. The standard deviations were then estimated by dividing the difference between the mean and lower limit by the appropriate value of k.

The specimens tested in helium showed no extreme deviations from their expected values and were included along with the specimens tested in hydrogen.

The pancake forging specimen (880493), tested at -423°F was substantially off the curve, with an actual Ki of 33.6 at 10^4 cycles compared with an expected value of 28.6. It is therefore shown separately on Page 4, and its design allowable was calculated by assuming the same standard deviation as the die forgings. The stress intensity for pancake forgings at 10^3 cycles was estimated by extrapolating from 10^4 parallel to the die forging curve, and the corresponding design allowable was again calculated by assuming the same standard deviation. Because of the extrapolation, this one data item has been downgraded to category "D".

c. Crack Growth Rate

(1) General

Instantaneous crack growth rates (da/dN) in Micro-inches per cycle were obtained during cyclic testing. Paired data for crack growth rate vs average Ki were provided by Boeing in the form of computer printouts. Up to 20 data points were given for each cyclic specimen.

The data are plotted on log-log paper in Reference 2. The growth rate increases with stress intensity in an approximately linear manner until, at about 90 KSI $-\sqrt{in}$, there is a fairly abrupt increase in the slope.

The relationship could be represented by a quadratic equation over the entire range or by two straight lines of different slopes, each representing a portion of the data. The latter model was selected because it provides a simpler and more useful regression equation.

The computer program MULFIT was used to perform regression analysis. Each temperature was handled separately.

(2) Room Temperature

At room temperature the specimen tested in helium exhibited a slightly slower crack growth than the specimens tested in hydrogen. The helium data were excluded from the analysis to provide a more conservative estimate for crack growth rate in hydrogen.

The data were divided into two groups to represent the two different slopes, and separate regression analysis runs made for the two groups. A brief series of iterations was required to locate the boundary of the groups close to the intersection of the two regression lines. A reasonable boundary was located at 90 KSI $-\sqrt{\text{in.}}$

Regression analysis results for the two goups were:

	n	Regression Equation	s_e*	R^2
for $Ki \leq 90$:	80	$\log (da/dN) = -3.863 + 3.5045 \log (Ki)$	.1645	.918
for $Ki > 90$:	27	$\log (da/dN) = -9.861 + 6.5466 \log (Ki)$	.1251	.896

* in logarithmic units

The standard errors of estimate were found to be homogeneous for the two groups and were combined to obtain a pooled s_e of .156 based on 103 degrees of freedom.

The expected value of the log of growth rate was calculated from these two equations for a series of stress intensity levels. The <u>upper</u> 99/95 limits were determined as Expected Value + ks_e, where the k values correspond with calculated effective sample size and f = 103.

Finally both the expected values and the 99/95 limits were converted to anti-log form (micro-inches per cycle).

3. -160°F

At -160°F, data points in the upper slope region were few in number and were extremely erratic. Regression analysis was, of necessity, confined to the determination of a single straight line for the region of $Ki \leq 90$ KSI $-\sqrt{\text{in.}}$ The specimen tested in helium yielded results that were typical of the three specimens tested in hydrogen and therefore these results were included in the same analysis.

The results were:

	n	Regression Equation	s_e	R^2
for $K \leq 90$	43	$\log (da/dN) = -4.733 + 3.9115 \log x$	.0887	.968

The calculation of expected values and design allowables followed the procedure used for the room temperature data.

(4) -423°F

At -423°F the pancake forging specimen exhibited a substantially lower crack growth rate at all Ki levels in comparison with the die forgings. A change in slope is indicated in the vicinity of 45 KSI - $\sqrt{\text{in.}}$ for both forging types, but the number of data points is too small to determine the two separate regression lines for the purpose of calculating design allowables. As an alternate, the quadratic model was used over the entire data range. In this analysis, forging type was input as a dummy variable, x_2, which was assigned a value of zero for die forgings and of one for pancake forgings. This technique results in two regression lines having the same slopes but different intercepts.

The results were as follows:

n	Regression Equations*	s_e	R^2
20	$\log(da/dN) = 60.614 - 83.453 \log x_1 + 29.253 (\log x_1)^2 - .794 x_2$	.327	.901

For die forgings, $x_2 = 0$ and the last term drops out. For pancake forgings, $x_2 = 1$ and the last term becomes -.794 which may be combined with the intercept 60.614 to produce a curve parallel with the first.

The regression equation was used to determine expected growth rates and 99/95 design allowables in the same manner as the other two temperatures. Pancake and die forgings are listed separately.

* x_1 = Ki; x_2 = forging type.

Linear regression equations for the two slopes were also calculated and are presented for information even though they were not used for calculating design allowables. The division of the data is based on a boundary value for da/dN of 100 micro-inches/cycle.

da/dN	n	Regression Equation *	s_e	R^2
≤ 100	11	$-30.217 + 19.857 \log x_1 - 1.187\, x_2$	.409	.789
> 100	9	$-6.578 + 5.257 \log x_1 - .466\, x_2$	.083	.924

* x_1 = Ki (KSI $-\sqrt{\text{in}}$); x_2 = Forging Type (x_2 = 0 for Die, x_2 = 1 for Pancake)

(5) Plots

Crack growth rate curves for the three temperatures are presented in Figures 1 - 4. Both the expected values and design allowables are shown.

d. Data Categories

The data are all categorized as "C" except for one "D" entry discussed above. Although the sample sizes for crack growth rate data far exceed the requirements for "A" data, these represent multiple observations per specimen, rather than an adequate number of specimens.

The intent of the data analysis and classification procedures is to make adequate allowance for material variability. To be consistent with this intent, the number of specimens, rather than the total number of observations is the logical criterion.

In the few cases where the specimen matrix meets the requirements of TD-28, there is still insufficient representation of material lots and forging configurations for such factors to be investigated adequately, and allowances made for their effects. Therefore none of the data have been classified above category "C".

3. REFERENCES

(1) Metallurgical Testing Corporation Test Report, Laboratory No. 12-109F, 18 January 1972

(2) "Flaw Growth of Various NERVA Engine Materials", by W. D. Bixler, Aerospace Group, The Boeing Company, March 1972.

Ti 5Al 2.5Sn ELI Die Forging   CRACK GROWTH RATE @ ROOM TEMPERATURE (GH2, 100 PSIG)

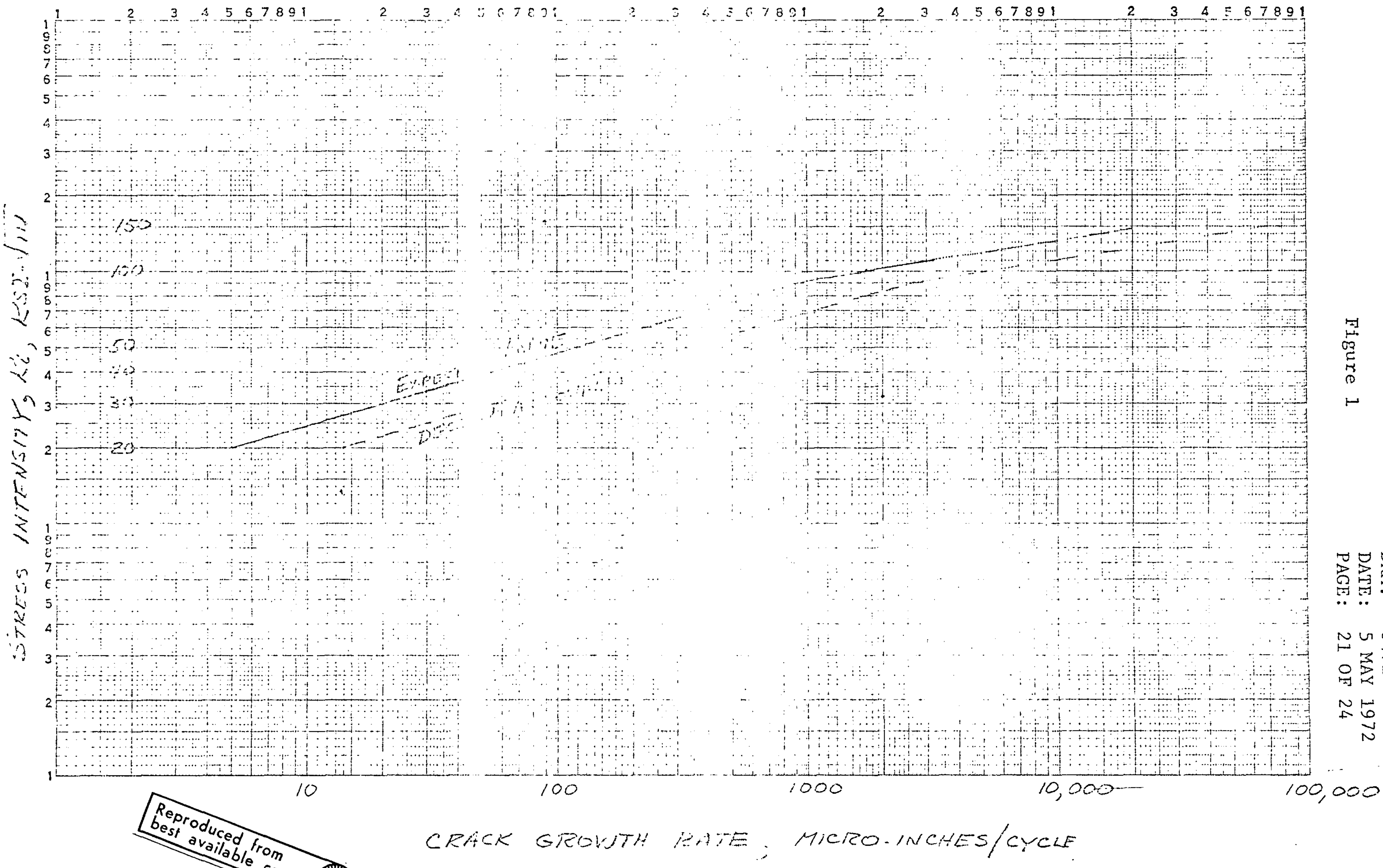
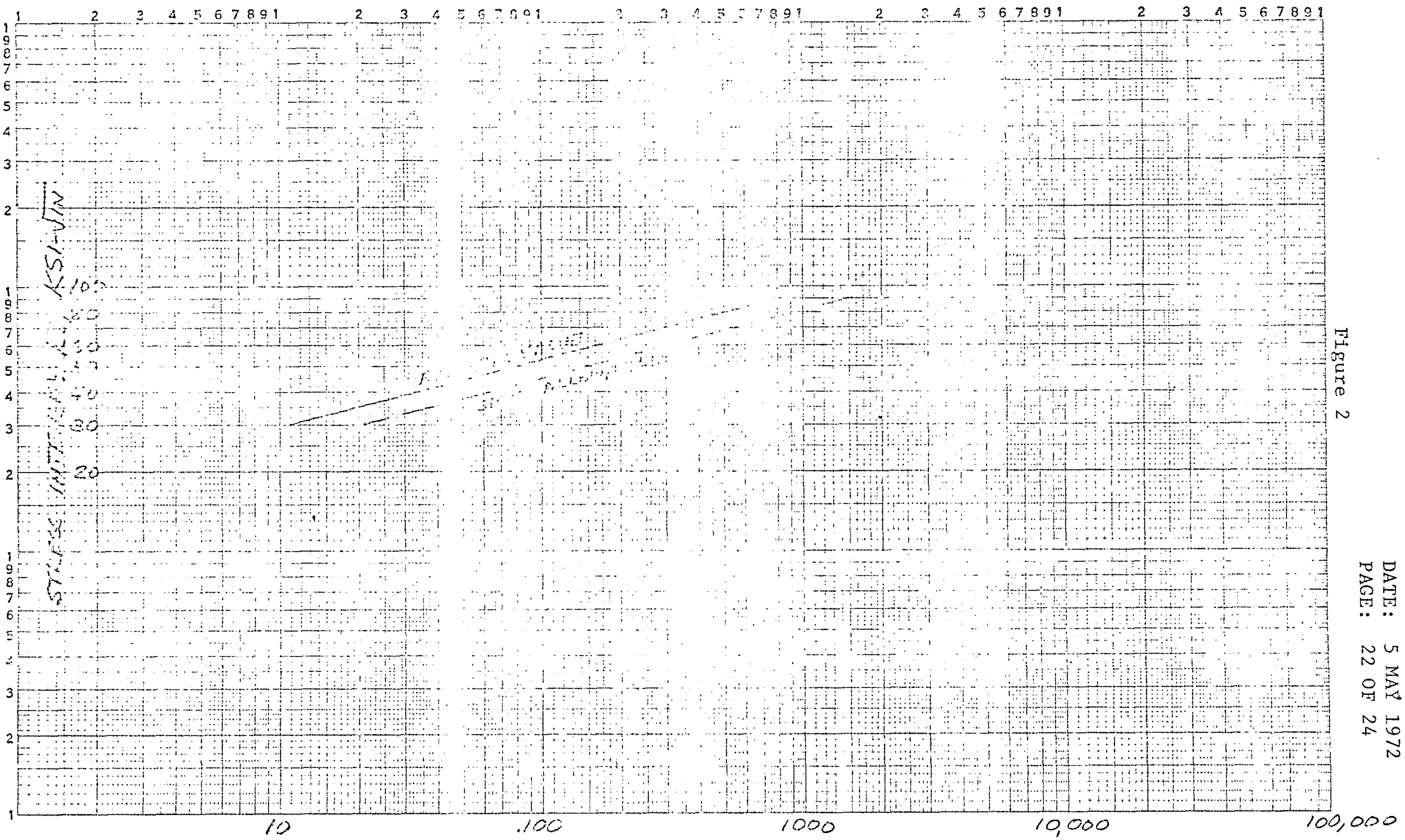


Figure 1

NO. 340-L35 DIETZGEN GRAPH PAPER
LOGARITHMIC
3 CYCLES X 5 CYCLES

EUGENE DIETZGEN CO.
MADE IN U. S. A.

Ti 5Al 2.5Sn ELI Die Forging CRACK GROWTH RATE @ -160°F (GH_2, 1200 PSIG)



CRACK GROWTH RATE, MICRO-INCHES per CYCLE

Figure 2

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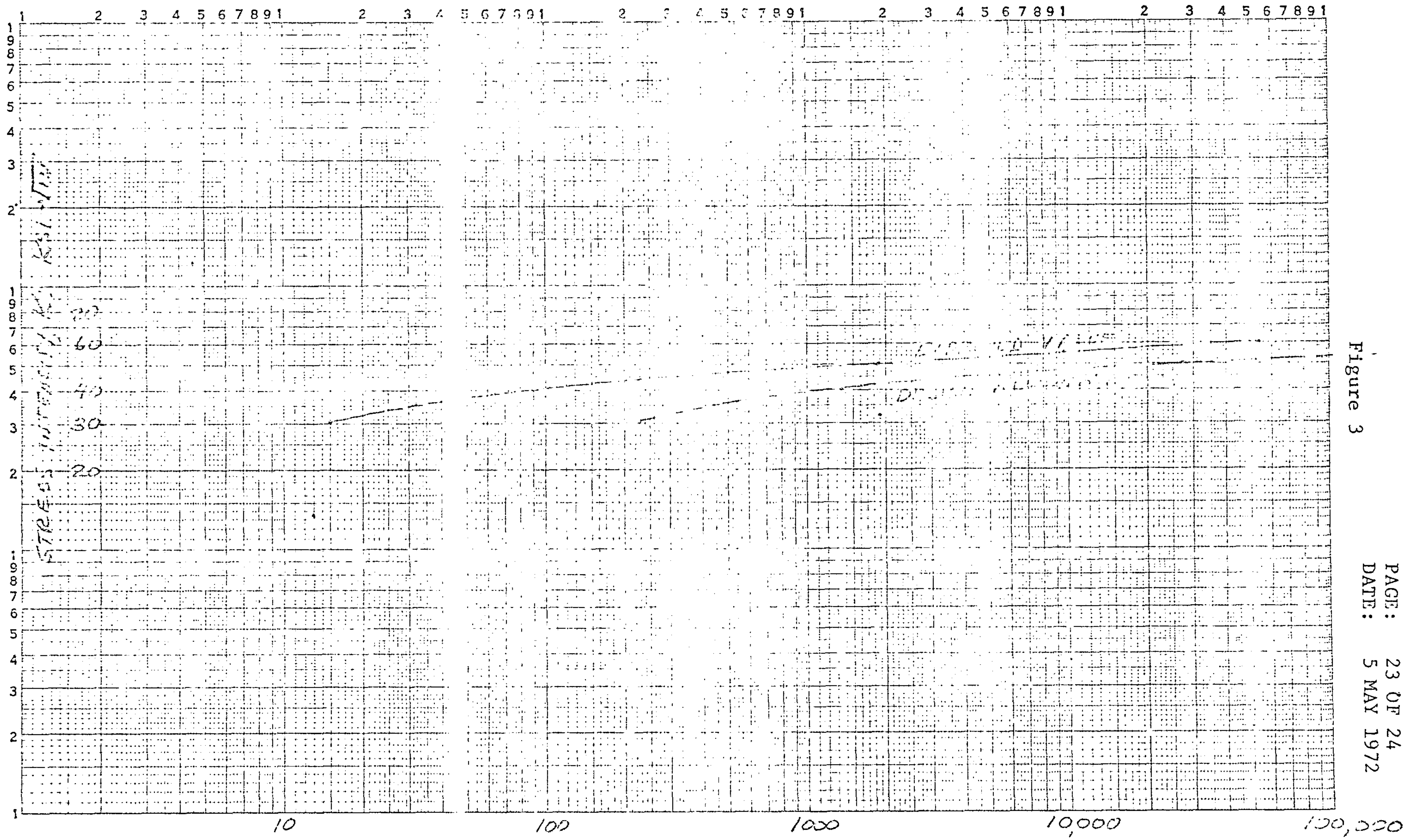
Ti 5Al 2.5 Sn ELI DIE FORGINGS CRACK [illegible] (LH_2)



CRACK GROWTH RATE, MICRO-INCHES PER CYCLE

Figure 3

Ti 5Al 2.5 Sn ELI

RATE @ -423 (LH2)

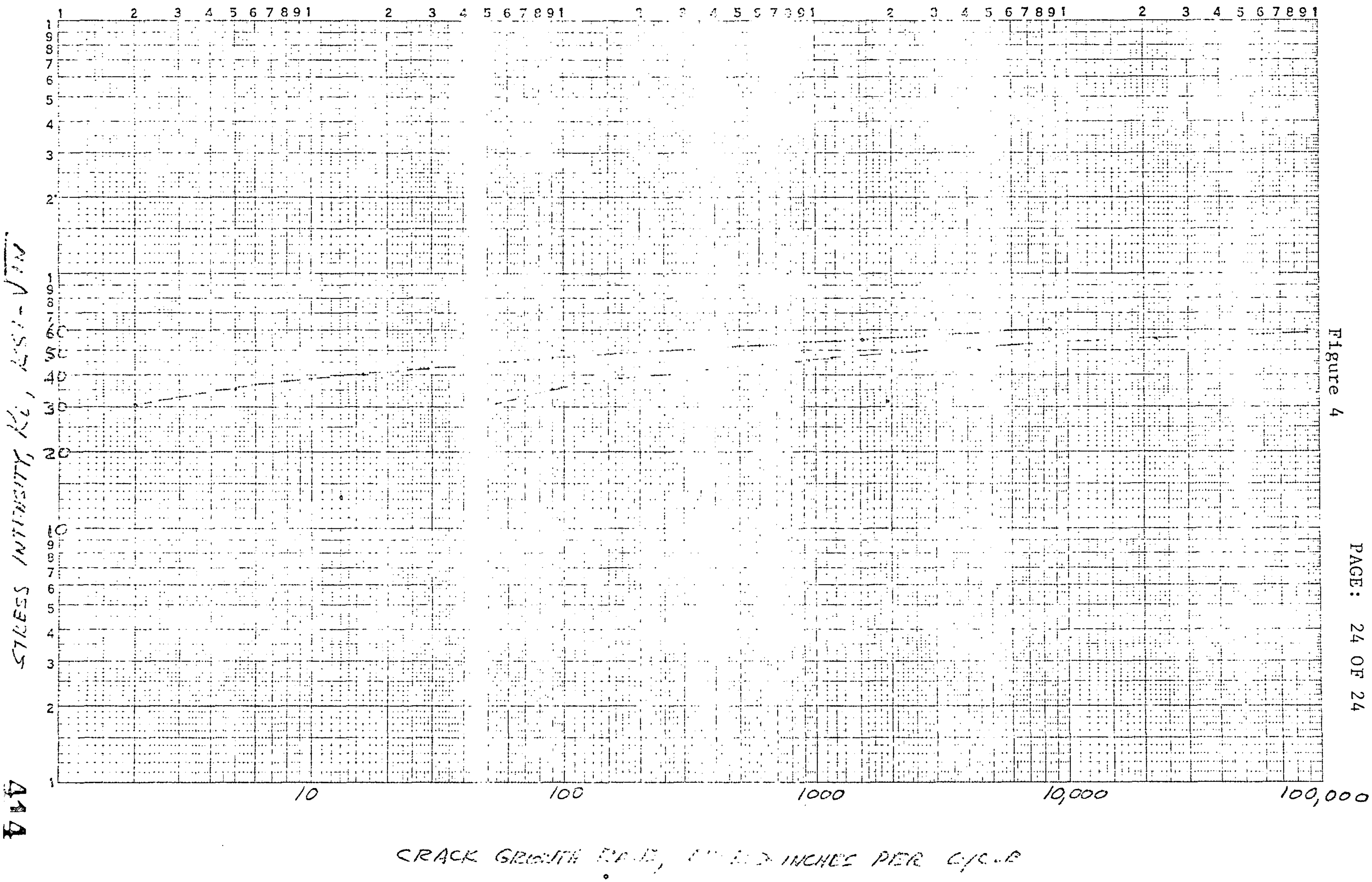


Figure 4

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N8300R:72-103
May 1972

ENCLOSURE 21

TITANIUM SECTION OF FINAL REPORT, "FLAW GROWTH OF VARIOUS NERVA ENGINE MATERIALS", CONTRACT P.O. N-014999, BOEING COMPANY, SEATTLE, WASHINGTON

4.8 5Al-2.5 Sn (ELI) Titanium

4.8.1 RT Tests

Three static fracture tests were conducted at RT in 100 psig gaseous hydrogen; one from one die forging and two from another die forging. The detailed results of these tests are presented in Table 22. K_Q values ranged from 97.4 to 108.4 ksi$\sqrt{in}$ and $(K_I)_{max}$ values ranged from 116.8 to 126.8 ksi$\sqrt{in}$. The tests did not meet the ASTM-E399-70T requirements for thickness. Based on an assumed RT yield strength of 94 ksi, K_Q would have to have been $\leq$ 59.5 ksi$\sqrt{in}$ to be considered a valid K_{Ic} test. Although no valid plane strain fracture toughness values were determined for the 5Al-2.5Sn (ELI) titanium at RT, the results obtained do show little variability of static fracture properties of the die forgings tested. The effect of 100 psig hydrogen on the static fracture properties of the titanium was not assessed since tests in helium were not conducted.

1-a

A total of 7 specimens were cyclic tested at RT to essentially failure; one in 100 psig gaseous helium and 6 in 100 psig gaseous hydrogen (one from one die forging, 2 from another die forging and 4 from yet another die forging). All of the tests were conducted at 5 cps and the results are presented in Figure 31 and Table 23. Figure 31 indicates that a single curve adequately represents the variation of K_{Ii} with N in the hydrogen environment. The single specimen tested in gaseous helium demonstrated a very slightly longer life. The results of the instantaneous da/dN for the specimens tested in helium and hydrogen are presented in Figures 32 and 33, respectively. The scatter band on the helium da/dN data lies within the scatter band of the hydrogen da/dN data but tends to the slow side. Although it appears that 100 psig hydrogen might have a very slight effect on the cyclic life and crack growth rates at 5 cps, additional tests would have to be conducted to verify this point since this observation is based on only one test specimen. Variability of material properties from die forging to die forging might account for the slight differences observed. It is a known fact that 5Al-2.5Sn (ELI) titanium forging material is susceptible to high pressure (1400 psig) gaseous hydrogen at RT as observed in Reference 1. The Reference 1 work indicated sustained load thresholds as low as 20 ksi $\sqrt{in}$ for the high pressure hydrogen, but it is not known how the susceptibility varies with pressure for this material. In conclusion, it appears that the cyclic life and flaw growth rates at RT are only very slightly affected, if at all, by 100 psig gaseous hydrogen compared to helium for the titanium material when tested at 5 cps.

4.8.2 -160°F Tests

Two static fracture tests were conducted at -160°F in 1200 psig gaseous hydrogen, each from a different die forging. The detailed results of these tests are presented in Table 22. K_Q values of 84.9 and 86.0 ksi $\sqrt{in}$ and $(K_I)_{max}$ values of 84.9 and 88.5 ksi $\sqrt{in}$ were obtained. The tests did not quite meet the ASTM-E399-70T requirement for thickness. Based on a -160°F yield strength of 128 ksi, K_Q would had to have been ≤ 81.0 ksi $\sqrt{in}$ to be considered a valid K_{Ic} test per ASTM. The flat appearance of the fracture face plus the failure abruptness of the load/displacement curves, leads one to believe that the tests were valid. The results obtained do show little variability of static fracture properties of the two die forgings tested. The effect of 1200 psig hydrogen on the static fracture properties of the titanium was not assessed directly but the load/displacement records indicate that essentially no flaw growth took place prior to failure and therefore it is felt that there is no effect.

A total of 4 specimens were cyclic tested at -160°F to failure; 1 in 1200 psig gaseous helium and 3 in 1200 psig gaseous hydrogen (2 specimens each from 2 die forgings). The tests were conducted at 5 cps and the results are presented in Figure 34 and Table 24. Figure 34 indicates that a single curve adequately represents the variation of K_{Ii} with N in either environment. The results of the instantaneous da/dN for the specimens tested in helium and hydrogen are presented in Figures 35 and 36, respectively. The scatter band on the helium da/dN data encompasses the hydrogen da/dN results with the exception of one hydrogen specimen at very high stress intensity levels. This specimen was cycled from a very low K_{Ii} of 22.3 ksi $\sqrt{in}$ and at a stress intensity of about 65 ksi $\sqrt{in}$ the crack had extended to the point that excessive plastic deformation was taking place and this resulted in the high growth rates. From these results, it appears that the cyclic life and flaw growth rates are unaffected by high pressure hydrogen compared to high pressure helium at RT for 5Al-2.5 Sn (ELI) titanium material. Additional supporting evidence of the immunity of this titanium to gaseous hydrogen at -160°F is presented in Reference 1 sustained load tests at this temperature.

4.8.3 -423°F Tests

Essentially 4 static fracture tests were conducted at -423°F in zero psig liquid hydrogen; one each from 2 die forgings and one each from 2 pancake forging slices. The detailed results of these tests are presented in Table 22. The two die forging specimens had K_Q values of 53.4 and 55.2 ksi $\sqrt{in}$ while one static fracture pancake forging specimen exhibited a value of 69.4 ksi $\sqrt{in}$. The remaining pancake forging specimen was initially intended for use as a cyclic specimen, but failed within 5 cycles while increasing the load to the desired cyclic load. This specimen demonstrated a K_Q value of 50.5 ksi$\sqrt{in}$, considerably below the other pancake forging specimen test. All of the tests did meet the ASTM-E399-70T requirements. Based on an assumed -423°F yield strength of 168 ksi, a K_Q value of $\leq$ 106.2 ksi$\sqrt{in}$ would be considered a valid K_{Ic} test. It should be mentioned that the strain rate to failure for the specimen intended for cyclic testing was considerably higher than that of the standard static fracture test. The loading rate normally was 8500 lb/minute, whereas the low toughness specimen was loaded at almost 500 times that rate. This difference in loading rates could account for the difference in toughnesses. One other difference between the two pancake forging specimens was the appearance of the fracture faces. The low toughness specimen exhibited a smoother texture macroscopically than the other specimen. Both specimens were examined microscopically but only very minor differences were observed. Additional tests would be required to definitely establish the reason for the low toughness observed.

Four specimens were cyclic tested at -423°F in zero psig liquid hydrogen; 2 specimens from one die forging, one specimen from another die forging and one specimen from a pancake forging. All of the tests were conducted at 5 cps and the results are presented in Figure 37 and Table 25. Grouping the results based on whether or not the specimen was made from a die forging or a pancake forging, resulted in single curves representing the variation of K_{Ii} with N. The single pancake forging specimen tested exhibited a very rough textured fracture face. Instantaneous da/dN results of these specimen tests are presented in Figure 38. The pancake forging specimen exhibited slower fatigue crack growth rates than the die forging specimens.

4.

5.0 OBSERVATIONS

(1) The static fracture results were unaffected by 1200 psig high purity gaseous hydrogen compared to 1200 psig gaseous helium at RT for Armco 22-13-5 steel, phosphor bronze, A286 steel, Hastelloy X and 347 stainless steel. Valid fracture toughness values were not obtained in the above tests due to limited material thickness.

(2) An apparent hydrogen effect was observed in the static fracture testing of 9310 carburized steel when considerable time dependent growth occurred during loading to failure in 1200 psig gaseous hydrogen at RT. The growth on this specimen was distinguishable on the fracture face as well as indicated on the load/crack opening displacement record. Using the flaw size at fracture plus the load at failure resulted in an apparent toughness equal to that observed in a helium environment. An apparent K_{Ic} equal to about 120 ksi$\sqrt{in}$ was observed at RT in helium for the 9310 steel. At -423°F in liquid hydrogen this material exhibited a K_{Ic} value of 32 ksi$\sqrt{in}$.

(3) The static fracture tests for 5Al-2.5 Sn (ELI) titanium in 100 psig gaseous hydrogen at RT were not valid K_{Ic} tests due to limited material thickness available. The two different die forging materials tested at RT did not indicate any significant variability in apparent fracture toughness. The static fracture tests conducted at -160°F in 1200 psig gaseous hydrogen were essentially valid K_{Ic} values. These results also demonstrated uniformity of toughness results between the two die forgings tested. The fracture tests at -423°F in liquid hydrogen involved specimens fabricated from a pancake forging as well as two die forgings. All fracture toughness tests at -423°F resulted in valid K_{Ic} results with the pancake forging demonstrating a higher toughness than the die forgings.

(4) The cyclic life and flaw growth rates were unaffected by 1200 psig gaseous hydrogen compared to 1200 psig gaseous helium at RT for Armco 22-13-5 and phosphor bronze.

(5) The cyclic life and flaw growth rates were apparently unaffected by 1200 psig gaseous hydrogen at RT for A286 steel tested at 5 cps. A single specimen tested at 1 cps in hydrogen had flaw growth rates slightly higher than that observed in either hydrogen or helium at 5 cps. This could either indicate a slight hydrogen effect or a strain rate sensitivity phenomenon. Additional specimens would have to be tested to establish this point.

(6) The cyclic life and flaw growth rates were moderately affected by the 1200 psig gaseous hydrogen at RT for Hastelloy X and 347 stainless steel. For Hastelloy X, a single specimen tested at 1 cps showed significantly higher flaw growth rates than specimens tested at 5 cps in hydrogen. The 347 stainless steel did not show this dependence of flaw growth rate with test frequency.

(7) The cyclic life and flaw growth rates were significantly affected by the 1200 psig gaseous hydrogen at RT for 9310 carburized steel. The flaw growth rate also increased when the test frequency was decreased. This hydrogen effect was observed at a stress intensity level as low as 11 ksi$\sqrt{in.}$

(8) The cyclic life and flaw growth rates were apparently slightly affected by 100 psig gaseous hydrogen at RT for 5Al-2.5 Sn (ELI) titanium as compared with gaseous helium when tested at 5 cps. The single specimen tested in gaseous helium demonstrated growth rates that fell within the gaseous hydrogen scatter band but was on the slow side which might indicate a slight hydrogen effect at 5 cps. Additional specimens would have to be tested to establish this point. The cyclic flaw growth rates obtained were very consistent between the 3 die forgings tested.

(9) The cyclic life and flaw growth rates were unaffected by 1200 psig gaseous hydrogen at -160°F for 5Al-2.5 Sn (ELI) titanium as compared with gaseous helium at 5 cps. The data scatter bands for both environments were essentially the same and consistent between the 2 die forgings tested.

(10) The cyclic life and flaw growth rates at $-423^{\circ}F$ in liquid hydrogen for 9310 carburized steel and 5Al-2.5 Sn (ELI) titanium were determined. Flaw growth rates for titanium specimens fabricated from die forgings were faster than for a specimen made from a pancake forging.

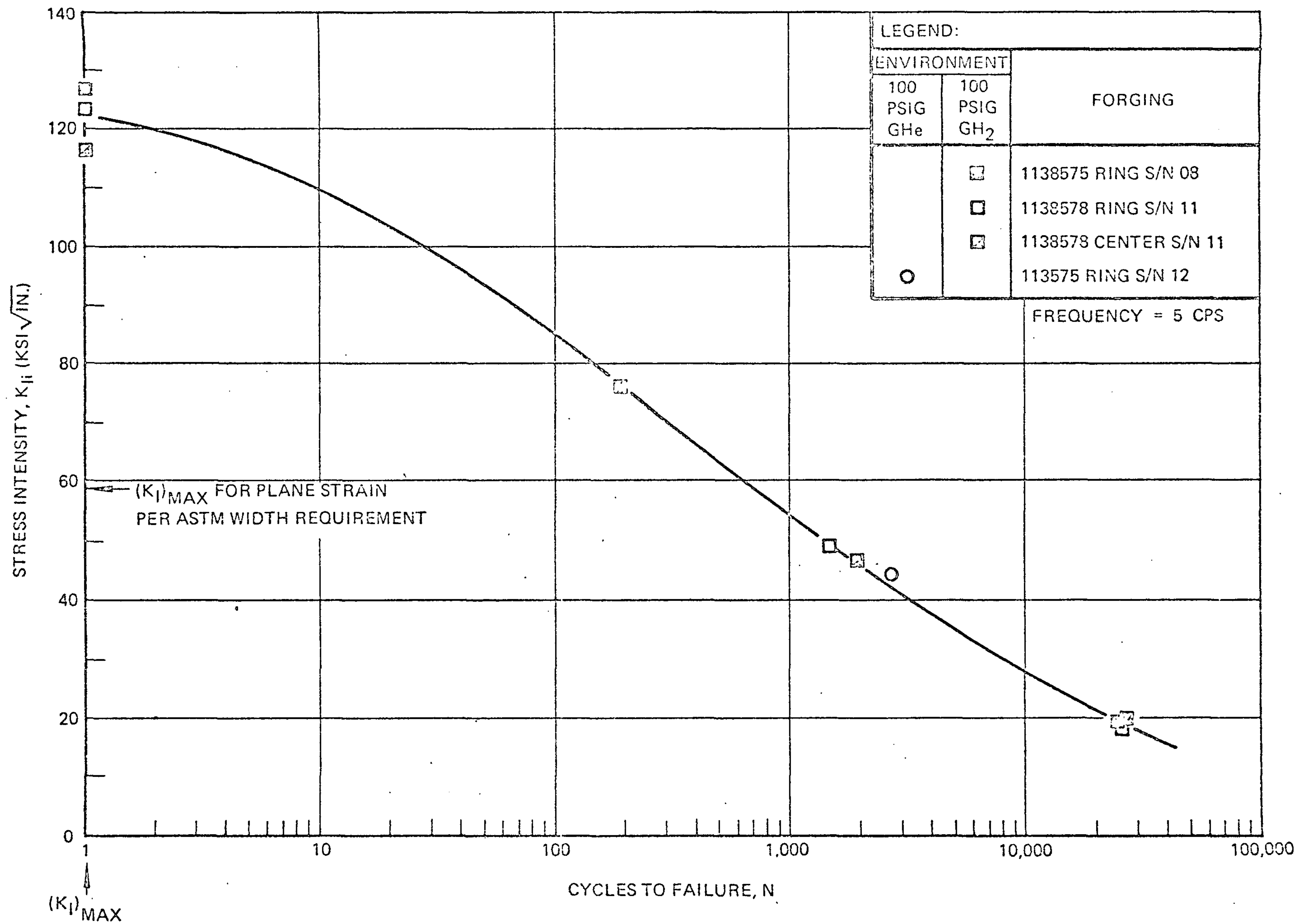

Figure 31: Cyclic Test Results of 5Al-2.5 Sn (ELI) Titanium at Room Temperature

423

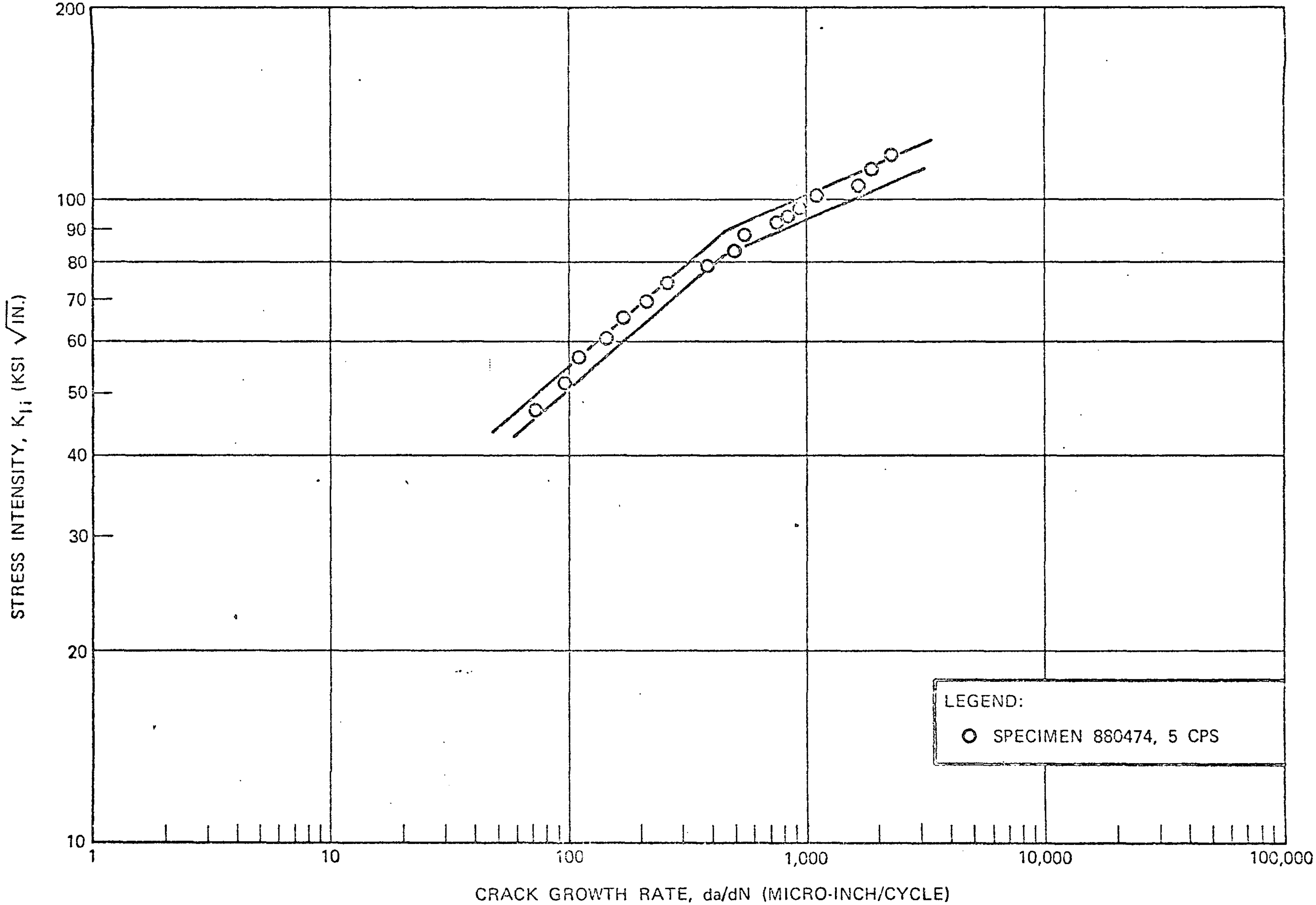

Figure 32: Growth Rate Results of 5Al-2.5 Sn (ELI) Titanium in 100 PSIG Gaseous Helium at Room Temperature

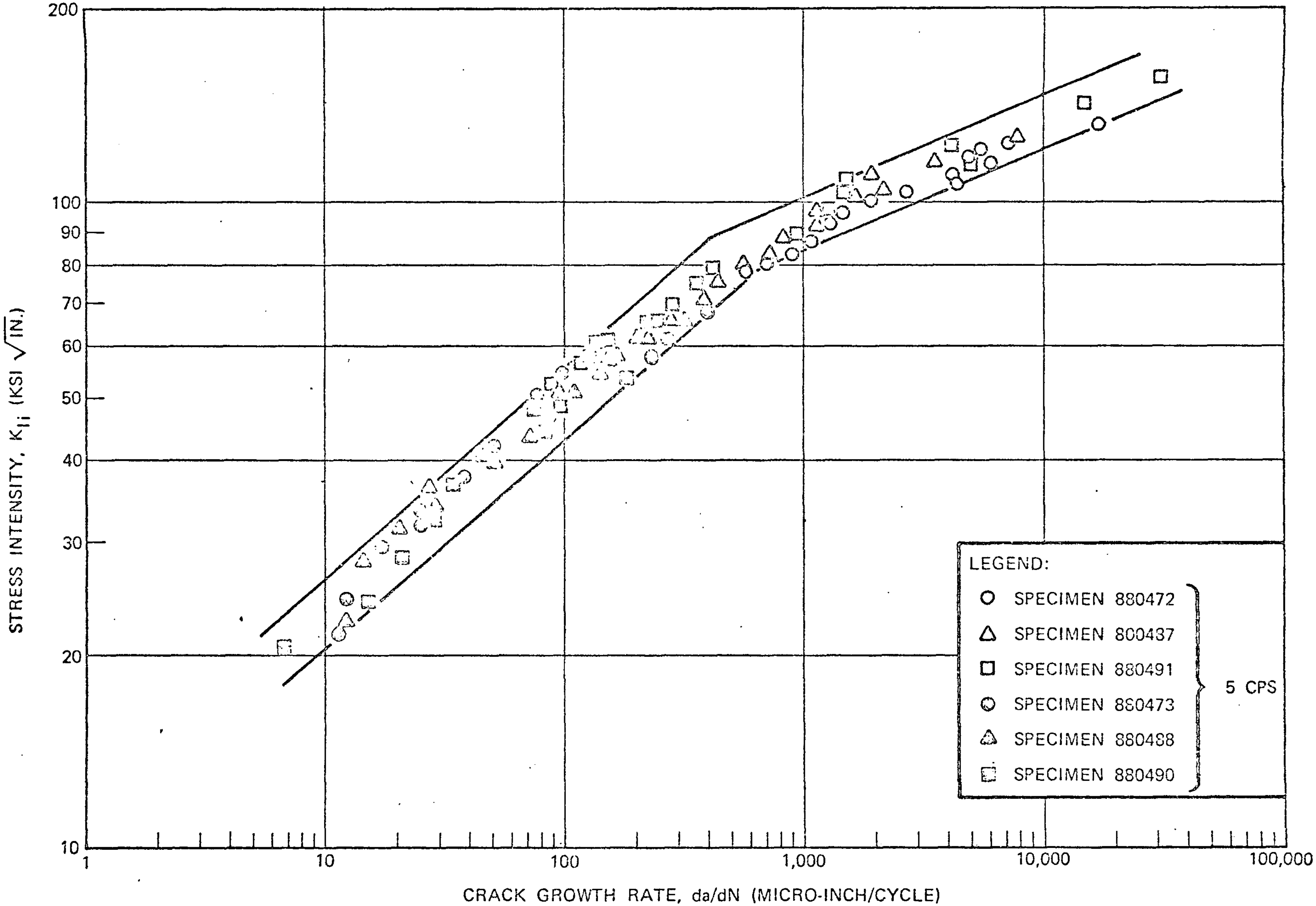

Figure 33: Growth Rate Results of 5Al-2.5 Sn (ELI) Titanium in 100 PSIG Gaseous Hydrogen at Room Temperature

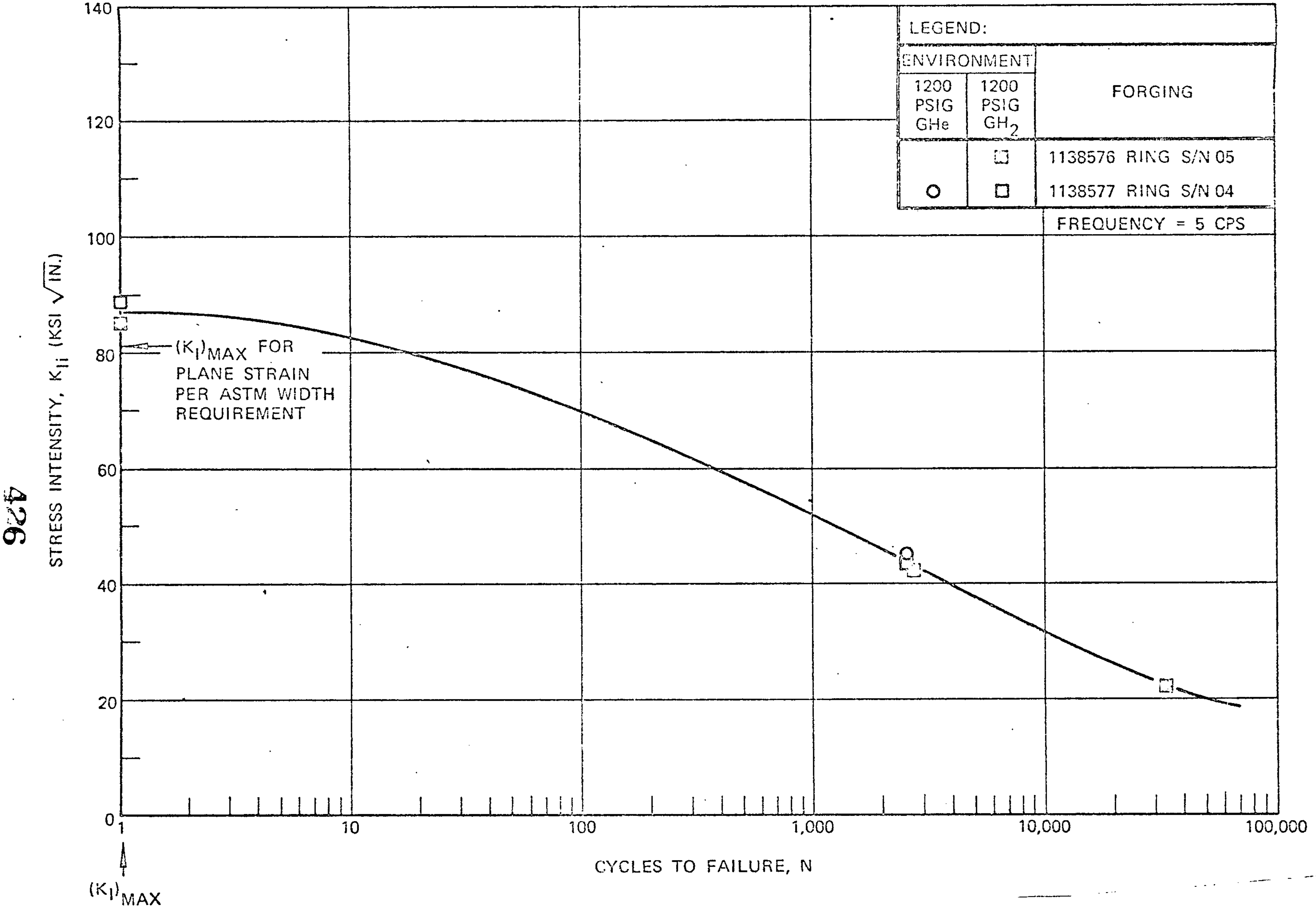

Figure 34: Cyclic Test Results of 5Al-2.5 Sn (ELI) Titanium at -160^{0}F

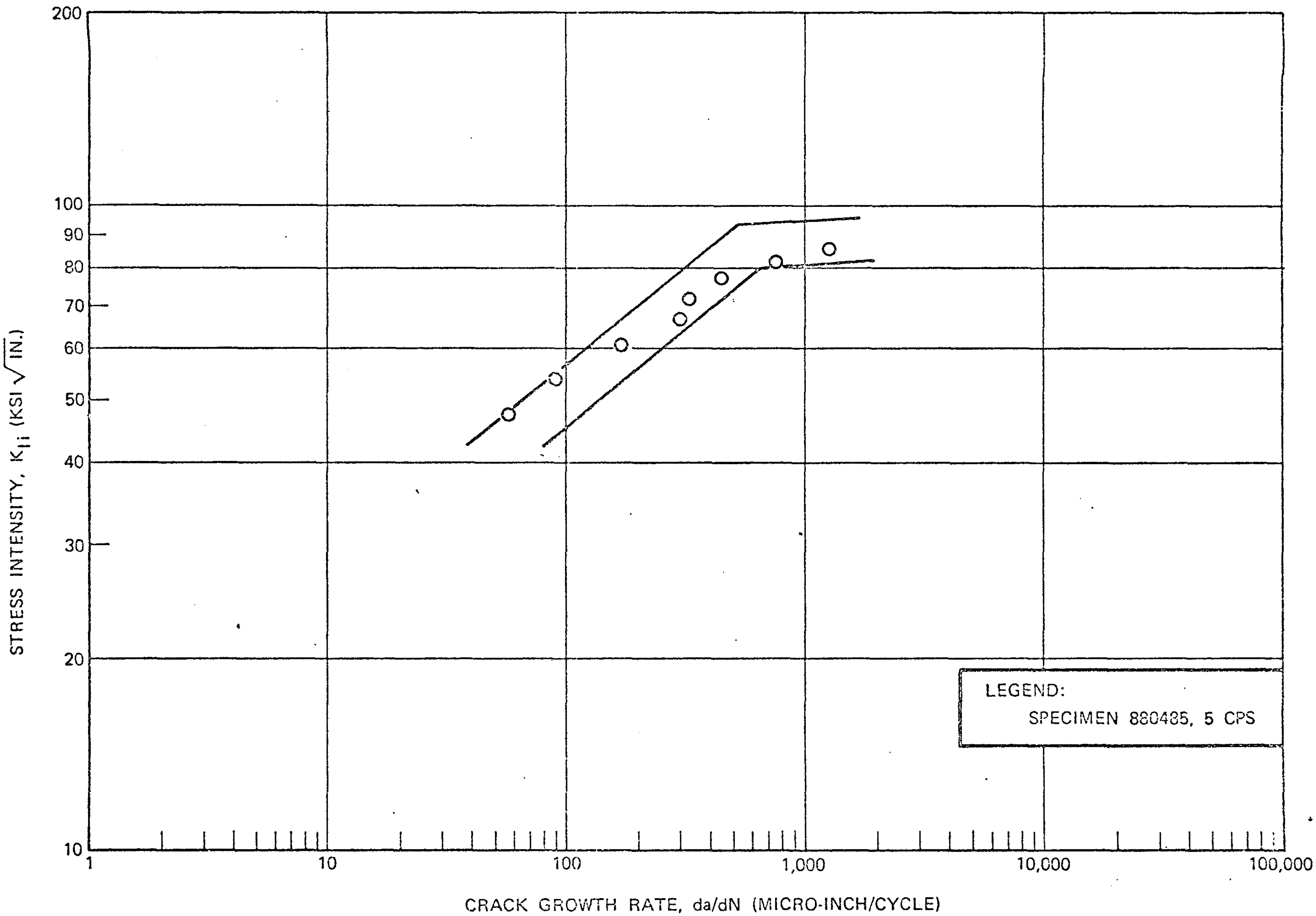

Figure 35: Growth Rate Results of 5Al-2.5 Sn (ELI) Titanium in 1200 PSIG Gaseous Helium at -160°F

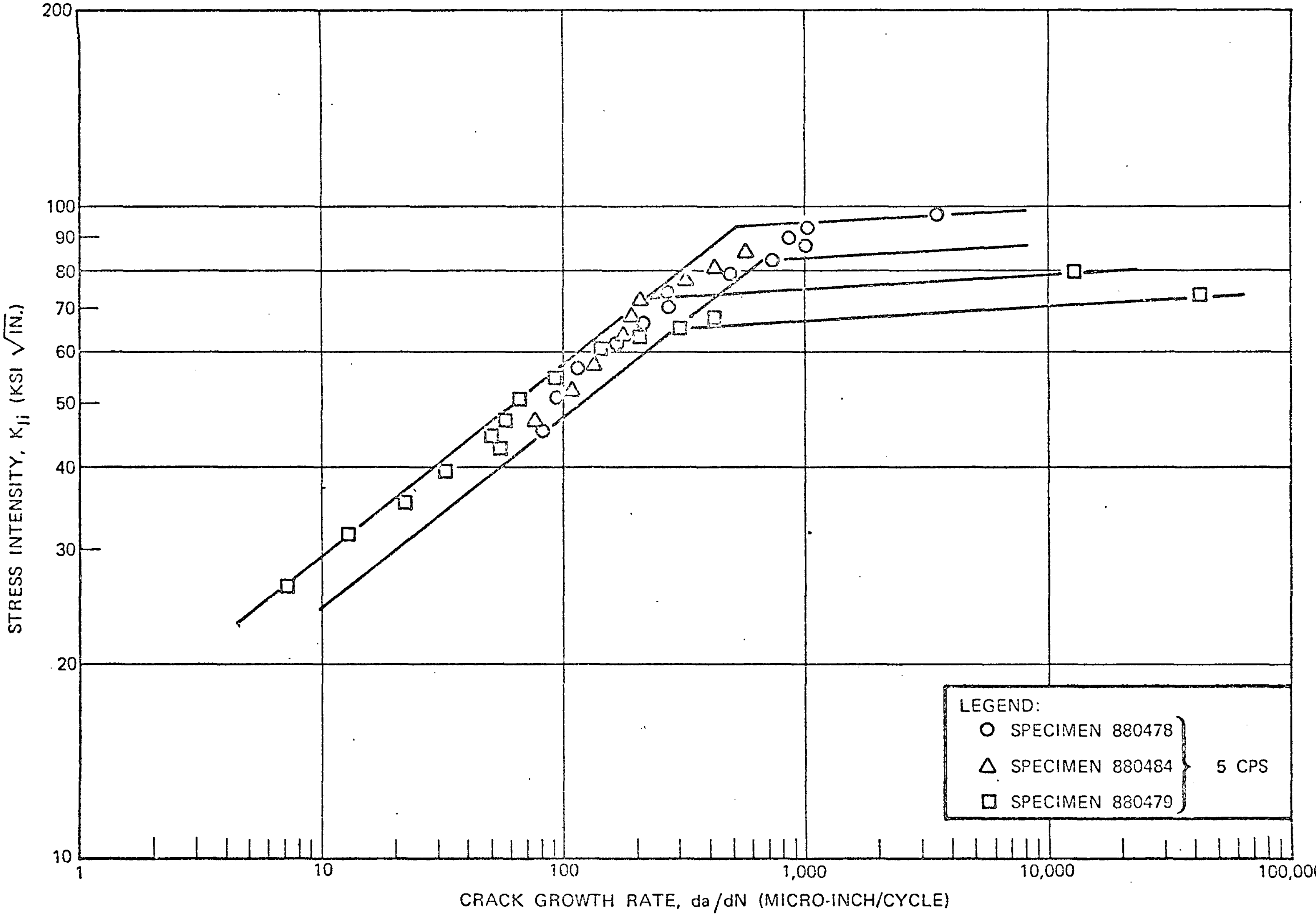

Figure 36: Growth Rate Results of 5Al-2.5 Sn (ELI) Titanium in 1200 PSIG Gaseous Hydrogen at -160°F

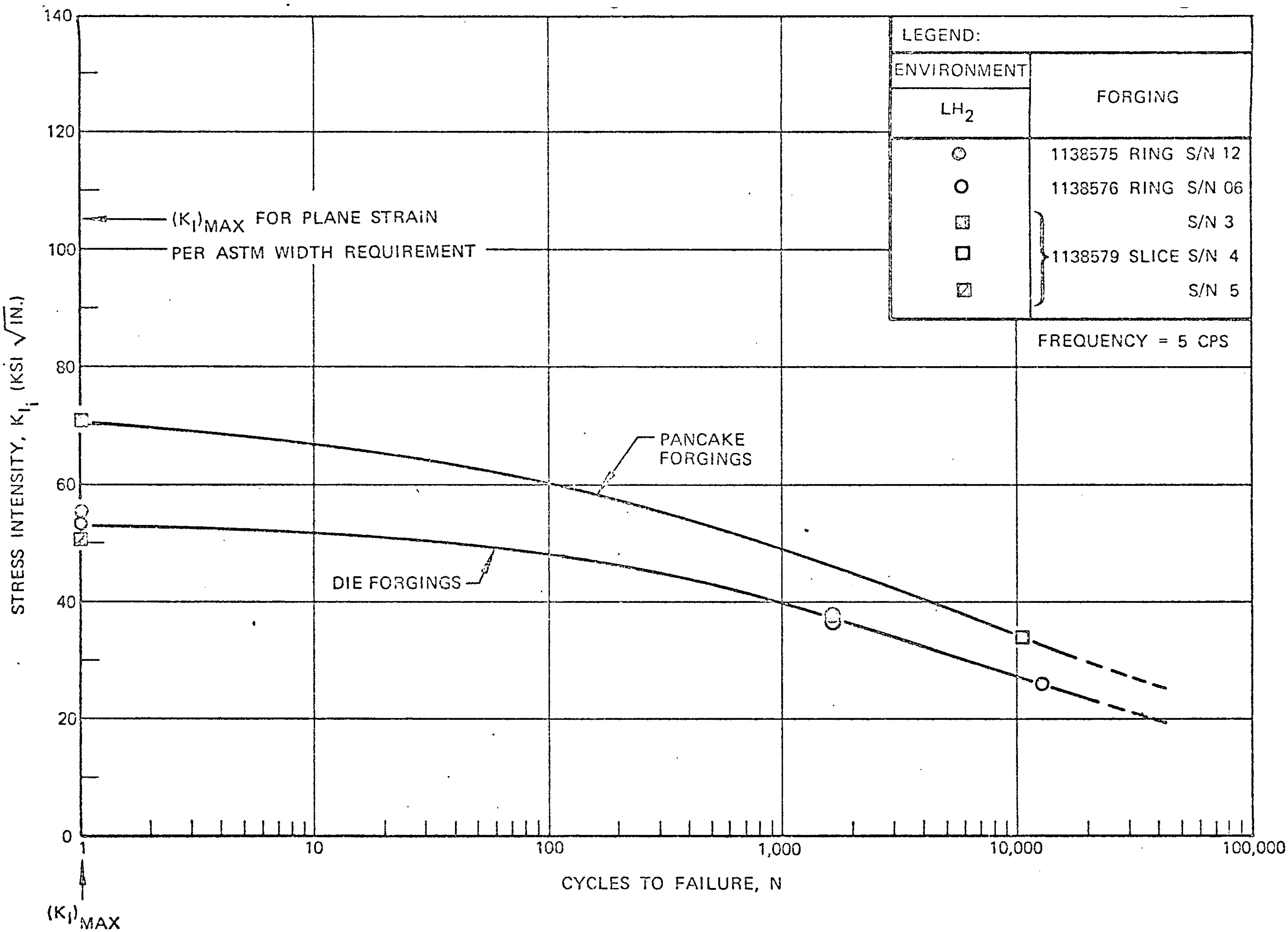

Figure 37: Cyclic Test Results of 5Al-2.5 Sn (ELI) Titanium in Liquid Hydrogen at -423°F

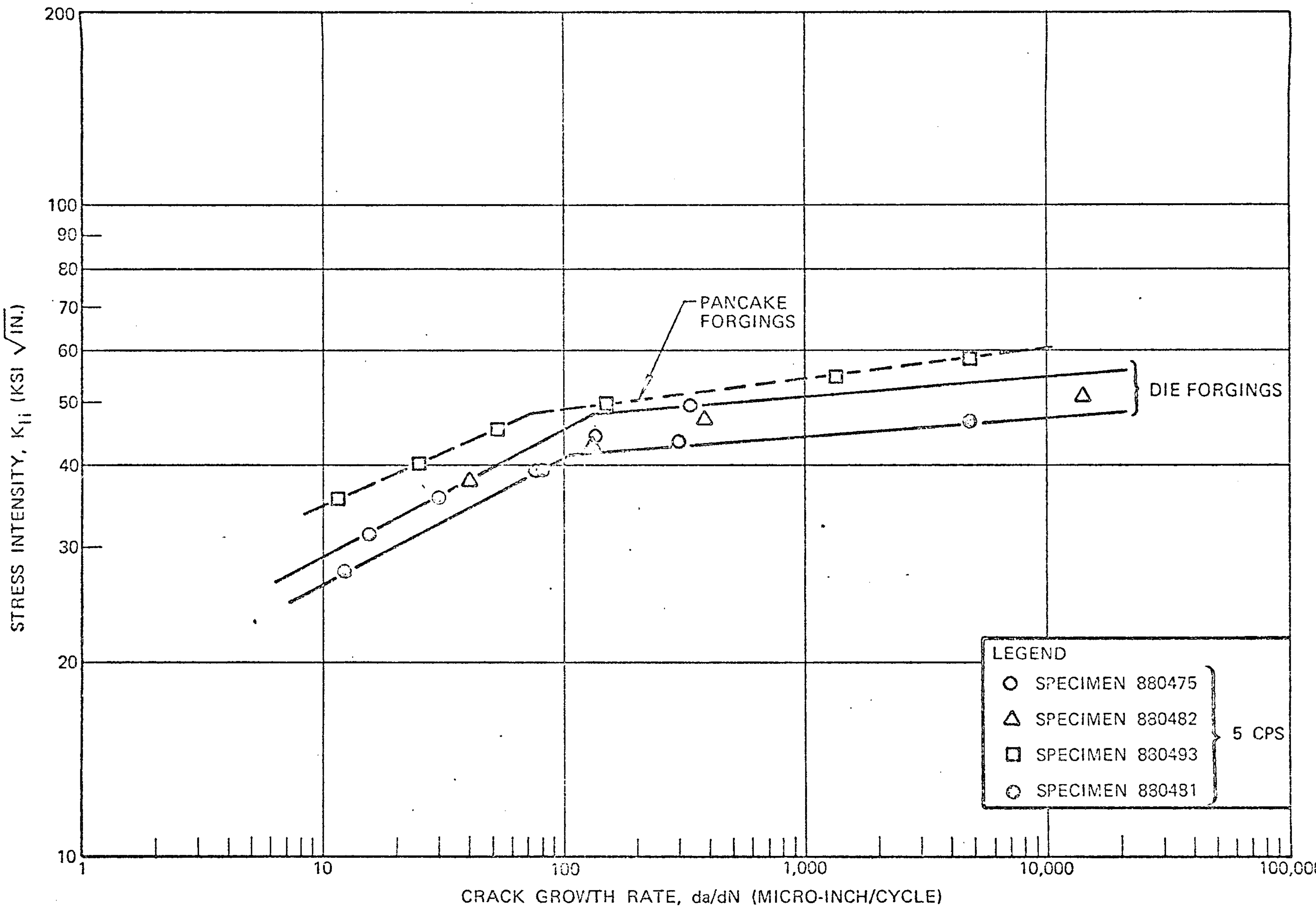

Figure 38: Growth Rate Results of 5Al-2.5 Sn (ELI) Titanium in Liquid Hydrogen at -423°F

Table 2: 5Al-2.5 Sn (ELI) Titanium Specimen/Forging Correlation

FORGING IDENTIFICATION			FRACTURE SPECIMEN IDENTIFICATION
PART NUMBER	ARCTURUS DIE NUMBER	SERIAL NUMBER	
1138575 (Ring Segment)	2915	08	1138365-104D/2915/08 S/N 880471
			1138365-104D/2915/08 S/N 880472
			1138365-104D/2915/08 S/N 880473
		12	1138365-104D/2915/12 S/N 880474
			1138365-104D/2915/12 S/N 880475
			1138365-104D/2915/12 S/N 880476
1138576 (Ring Segment)	2916	05	1138365-104D/2916/05 S/N 880477
			1138365-104D/2916/05 S/N 880478
			1138365-104D/2916/05 S/N 880479
		06	1138365-104D/2916/06 S/N 880480
			1138365-104D/2916/06 S/N 880481
			1138365-104D/2916/06 S/N 880482
1138577 (Ring Segment)	2917	04	1138365-104D/2917/04 S/N 880483
			1138365-104D/2917/04 S/N 880484
			1138365-104D/2917/04 S/N 880485
1138578 (Ring Segment)	2918	11	1138365-104D/2918/11 S/N 880486
			1138365-104D/2918/11 S/N 880487
			1138365-104D/2918/11 S/N 880488
1138578 (Whole Forging)	2918	11	1138365-104D/2918/11F S/N 880489
			1138365-104D/2918/11F S/N 880490
			1138365-104D/2918/11F S/N 880491
1138579 (Half Forging)	X292	3	1138365-104D/X292/3 S/N 880492
		4	1138365-104D/X292/4 S/N 880493
		5	1138365-104D/X292/5 S/N 880494

Table 21: Cyclic Tests of 9310 Carborized Steel in Liquid Hydrogen

SPECIMEN S/N	TEST PARAM-ETERS AT	CRACK LENGTH (INCHES) a_1	a_2	a_3	a_{avg}	MAX % "a" DEVIATION	a/w	P_{MAX} (KIPS)	FREQ (CPS)	TEST ENVIRONMENT	TEST DURATION (CYCLES)	PEAK TO PEAK FLAW OPENING (INCHES)	Y	K_I	REMARKS
880012	INITIATION	0.940	0.942	0.940	0.941	± 0.1	0.47	4.0	5	ZERO PSIG LH_2	118	0.006	13.0	25.2	Specimen Cycled to Failure
	TERMI-NATION	–	–	–	1.039**	–	0.54					0.009	15.4	32.1	
880014	INITIATION	0.998	1.005	1.006	1.003	-0.5	0.59	3.0	5	ZERO PSIG LH_2	1,406	0.005	13.9	20.8	Specimen Cycled to Failure
	TERMI-NATION	–	–	–	1.186**	–	0.59					0.011	17.7	28.8	
880013	INITIATION	0.964	0.942	0.947	0.951	+1.4	0.48	2.0	5	ZERO PSIG LH_2	22,840	0.003	13.1	12.8	Specimen Cycled to Failure
	TERMI-NATION	–	–	–	1.330**	–	0.67					0.013	22.5	26.0	

**ROUGH ESTIMATE

Table 22: Static Fracture Tests of 5Al-2.5 Sn (ELI) Titanium at RT, -160°F and -423°F

SPECIMEN S/N	TEST PARAM-ETERS AT	CRACK LENGTH (INCHES) a_1	a_2	a_3	a_{avg}	MAX % "a" DEVIATION	a/w	P (KIPS)	$\Delta_{0.8P}/\Delta_P$	TEST ENVIRONMENT	Y	K_I	REMARKS
880471	5% OFFSET SLOPE	1.016	1.035	1.031	1.027	-1.1	0.51	15.00	0.2	RT 100 PSIG GH_2	14.3	103.4	NO PRIOR TEST HISTORY
	P_{MAX}	1.016	1.036	1.031	1.027	-1.1	0.51	17.55	–		14.3	126.8	
880486	5% OFFSET SLOPE	1.037	1.054	1.055	1.048	-1.1	0.52	14.00	0.1		14.6	104.7	NO PRIOR TEST HISTORY
	P_{MAX}	1.037	1.054	1.055	1.049	-1.1	0.52	16.50	–		14.6	123.4	
880489	5% OFFSET SLOPE	1.030	1.030	1.010	1.022	-1.2	0.51	13.00	0.1		14.2	97.4	NO PRIOR TEST HISTORY
	P_{MAX}	1.030	1.030	1.010	1.022	-1.2	0.51	16.30	–		14.2	116.8	
880477	5% OFFSET SLOPE & P_{MAX}	1.050	1.066	1.057	1.058	±0.8	0.53	11.15	0.1	-160°F 1200 PSIG GH_2	14.8	84.9	NO PRIOR TEST HISTORY
880483	5% OFFSET SLOPE	1.012	1.009	1.024	1.015	+0.9	0.51	12.00	0.2		14.1	86.0	NO PRIOR TEST HISTORY
	P_{MAX}	1.012	1.009	1.024	1.015	+0.9	0.51	12.50	–		14.1	89.5	
880476	P_{MAX} [1]	1.042	1.052	1.038	1.044	+0.8	0.52	7.43	0.0	-423°F ZERO PSIG LH_2	14.6	55.2	NO PRIOR TEST HISTORY
880480	P_{MAX} [1]	1.040	1.050	1.064	1.051	+1.2	0.53	7.10	0.0		14.7	52.4	NO PRIOR TEST HISTORY
880492	5% OFFSET SLOPE	1.030	1.030	1.050	1.037	+1.3	0.52	9.45	0.1		14.4	69.4	NO PRIOR TEST HISTORY
	P_{MAX}	1.030	1.030	1.050	1.037	+1.3	0.52	9.60	–		14.4	70.5	(FRACTURE FACE VERY ROUGH)
880494	P_{MAX}	1.036	1.046	1.050	1.044	-0.8	0.52	6.80	–		14.6	50.5	FAILED UPON INCREASING LOAD ON 5TH CYCLE OF A CYCLIC TEST

[1] P_{MAX} REACHED PRIOR TO P_Q AT 5% OFFSET SLOPE

Table 23: Cyclic Tests of 5Al-2.5 Sn (ELI) Titanium at Room Temperature

SPECIMEN S/N	TEST PARAM-ETERS AT	CRACK LENGTH (INCHES) a_1	a_2	a_3	a_{avg}	MAX % "a" DEVIATION	a/w	P_{MAX} (KIPS)	FREQ (CPS)	TEST ENVIRONMENT	TEST DURATION (CYCLES)	PEAK TO PEAK FLAW OPENING (INCHES)	Y	K_I	REMARKS
880472	INITIATION	1.016	1.034	1.032	1.027	-1.1	0.51	10.5	5	100 PSIG GH_2	191	0.032	14.3	75.9	CYCLED TO FAILURE
	FAILURE	>1.33	>1.33	>1.33	>1.33***	—	0.67					>0.073*	22.5	136.5	
880487	INITIATION	1.060	1.068	1.059	1.062	+0.6	0.53	8.5** → 6.5	5	100 PSIG GH_2	276	0.025	14.9	65.3	SPECIMEN CYCLED FOR 276 CYCLES AT LOAD THAT DECREASED FROM 8.5 TO 6.5 KIPS, UNLOAD AND RE-STARTED AT 6 KIPS. TEST TERMINATED JUST PRIOR TO FAILURE
	TERMINATION	1.093	1.100	1.088	1.094	±0.5	0.55					0.021	15.5	52.6	
	INITIATION	1.093	1.100	1.088	1.094	±0.5	0.55	6.0			1,500	0.019	15.5	48.6	
	TERMINATION	1.520	1.540	1.522	1.529	+0.7	0.76					>0.062*	35.3	130.9	
880491	INITIATION	1.070	1.074	1.074	1.073	-0.3	0.54	6.0	5	100 PSIG GH_2	1,832	0.018	15.1	46.9	SPECIMEN CYCLED UNTIL Δ = 0.039", MARKED & RE-STARTED. TERMINATED JUST PRIOR TO FAILURE, VENTED & MARKED.
	TERMINATION	1.354	1.370	1.360	1.361	+0.7	0.68					0.039	24.0	83.8	
	INITIATION	1.356	1.374	1.363	1.364	+0.7	0.68				100	0.039	24.1	84.4	
	TERMINATION	1.640	1.600	1.598	1.613	+1.7	0.8					>0.074*	—	—	
880474	INITIATION	1.030	1.050	1.034	1.038	+1.2	0.52	6.0	5	100 PSIG GHE	2,719	0.018	14.5	44.2	TEST TERMINATED JUST PRIOR TO FAILURE, VENTED THEN MARKED.
	TERMINATION	1.504	1.510	1.500	1.505	±0.3	0.75					0.057	33.1	121.8	
880473	INITIATION	1.070	1.072	1.050	1.064	-1.3	0.53	2.5	5	100 PSIG GH_2	24,377	0.006	14.9	19.2	SPECIMEN CYCLED UNTIL Δ = 0.028", MARKED & RESTARTED. TERMINATED JUST PRIOR TO FAILURE, VENTED & MARKED.
	TERMINATION	1.544	1.546	1.530	1.540	-0.6	0.77					0.028	36.3	56.3	
	INITIATION	1.544	1.546	1.530	1.540	-0.6	0.77				395	0.030	36.3	56.3	
	TERMINATION	1.690	1.686	1.682	1.686	±0.2	0.8					0.058	—	—	
880488	INITIATION	1.054	1.054	1.046	1.051	-0.5	0.53	2.5	5	100 PSIG GH_2	22,000	0.006	14.7	19.8	SPECIMEN CYCLED FOR 22,000 CYCLES, UNLOADED. RESTARTED TEST & TERMINATED JUST PRIOR TO FAILURE.
	TERMINATION	1.364	1.374	1.350	1.363	-1.0	0.68					0.015	24.1	35.1	
	INITIATION	1.364	1.374	1.350	1.363	-1.0	0.68				3,517	0.015	24.1	35.1	
	TERMINATION	1.700	1.692	1.677	1.690	-0.8	>0.8					0.054	—	—	
880490	INITIATION	1.044	1.072	1.074	1.063	-1.8	0.53	2.5	5	100 PSIG GH_2	25,925	0.006	14.9	19.2	TEST TERMINATED JUST PRIOR TO FAILURE, VENTED & MARKED.
	TERMINATION	1.716	1.710	1.700	1.709	-0.5	>0.8					0.051	—	—	

* EXCEEDED RECORDER DISPLACEMENT FULL SCALE
** LOAD ERROR – FLUCTUATED
*** APPROXIMATELY

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Table 24: Cyclic Tests of 5Al-2.5 Sn (ELI) Titanium at -160°F

SPECIMEN S/N	TEST PARAM-ETERS AT	CRACK LENGTH (INCHES) a_1	a_2	a_3	a_{avg}	MAX % "a" DEVIATION	a/w	P_{MAX} (KIPS)	FREQ (CPS)	TEST ENVIRONMENT	TEST DURATION (CYCLES)	PEAK TO PEAK FLAW OPENING (INCHES)	Y	K_I	REMARKS
880478	INITIATION	1.024	1.000	1.011	1.012	±1.2	0.51	6.0	5	1200 PSIG GH_2	2,738	0.015	14.0	42.3	CYCLED TO FAILURE
	FAILURE	1.430	1.440	1.430	1.433*	+0.5	0.72					0.051	27.9	100.2	
880484	INITIATION	1.020	1.040	1.024	1.028	+1.2	0.51	6.0	5	1200 PSIG GH_2	2,540	0.015	14.3	43.4	TEST TERMINATED PRIOR TO FAILURE.
	TERMINATION	1.394	1.397	1.384	1.392	-0.6	0.70					0.040	25.5	90.3	
880485	INITIATION	1.040	1.050	1.050	1.047	-0.7	0.52	6.0	5	1200 PSIG GHE	1,926	0.017	14.6	44.8	SPECIMEN CYCLED UNTIL Δ = 0.022", MARKED & RESTARTED AND CYCLED TO FAILURE.
	TERMINATION	1.184	1.194	1.180	1.186	+0.7	0.59					0.022	17.7	57.7	
	INITIATION	1.184	1.194	1.180	1.186	+0.7	0.59				606	0.022	17.7	57.7	
	FAILURE	1.400	1.384	1.360	1.381*	-1.5	0.69					0.038	25.0	88.0	
880479	INITIATION	1.027	1.054	1.047	1.043	-1.5	0.52	3.0	5	1200 PSIG GH_2	23,507	0.008	14.5	22.3	SPECIMEN CYCLED UNTIL Δ = 0.010", RESTARTED AND CYCLED TO FAILURE.
	TERMINATION	1.200	1.229	1.212	1.211	-0.9	0.61					0.010	18.3	30.3	
	INITIATION	1.200	1.220	1.212	1.211	-0.9	0.61				9,737	0.011	18.3	30.3	
	FAILURE	1.600	1.600	1.590	1.597*	-0.4	0.80					0.060	42.5	80.5	

* APPROXIMATELY

Table 25: Cyclic Tests of 5Al-2.5 Sn (ELI) Titanium at -423°F

SPECIMEN S/N	TEST PARAM-ETERS AT	CRACK LENGTH (INCHES) a_1	a_2	a_3	a_{avg}	MAX % "a" DEVIATION	a/w	P_{MAX} (KIPS)	FREQ (CPS)	TEST ENVIRONMENT	TEST DURATION (CYCLES)	PEAK TO PEAK FLAW OPENING (INCHES)	Y	K_I	REMARKS
880475	INITIATION	1.044	1.044	1.024	1.037	-1.3	0.52	6.0	5	ZERO PSIG LH_2	1,600	0.013	14.4	36.7	TEST TERMINATED PRIOR TO FAILURE.
	TERMINATION	1.226	1.240	1.230	1.232	+0.6	0.62					0.021	19.0	52.6	
880482	INITIATION	1.032	1.040	1.036	1.036	±0.4	0.52	6.0	5	ZERO PSIG LH_2	1,601	0.014	14.4	36.7	CYCLED TO FAILURE.
	TERMINATION	1.233	1.233	1.233	1.233*	—	0.62					0.023	19.0	52.7	
880493	INITIATION	0.970	1.010	0.970	0.983	+2.7	0.49	6.0	5	ZERO PSIG LH_2	10,347	0.011	13.6	33.6	CYCLED TO FAILURE (FRACTURE FACE VERY ROUGH)
	TERMINATION	>1.38	>1.38	>1.38	>1.38*	—	0.69					>0.033	24.9	73.1	
880481	INITIATION	1.030	1.034	1.054	1.039	+1.4	0.52	3.5	5	ZERO PSIG LH_2	12,867	0.009	14.5	25.8	CYCLED TO FAILURE.
	TERMINATION	>1.35	>1.35	>1.35	>1.35*	—	0.68					0.022	23.4	47.6	

* APPROXIMATELY

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